DIRECT COMBUSTION SYSTEMS

TO

PRODUCE POWER FROM BIOMASS

FROM

WOOD, FOREST AND AGRICULTURAL CROP RESIDUE

Prepared by

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ABSTRACT

A review of the current state-of-the-art in direct combustion systems of biomass residues is directed to developing countries. "Off-the-shelf" conventional direct combustion systems are identified and vendor sources listed. The economics of in-country utilization of direct combustion systems are discussed. Constraints and applicability of the respective systems are reviewed along with an examination of the environmental problems associated with them.

Principals of biomass combustion, tables of biomass analyses for use as fuels and sample combustion calculations are given.

Handling and processing of biomass materials including drying to aid combustion is discussed. Material vendors of equipment needed to handle biomass materials are listed.

The appendix lists equipment manufacturers with addresses of their world wide agents.

Biomass fueled electric power plant advantages and disadvantages are discussed and as well as costs associated with a typical 16 mega Watt electric biomass fueled plant producing 50% cogenerated steam.

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DIRECT COMBUSTION OF BIOMASS

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DEFINITIONS AND ABBREVIATIONS

Generally speaking, the word "biomass" applies to virtually all types of plant growth material, whether it grows on land or within lakes and oceans. However, much of what is loosely referred to as biomass is not suitable for energy conversion by combustion.

The reasons for rejection of numerous plant materials as combustion fuel usually fall into one of two categories: value priority and preparation feasibility. Priority exclusions are often obvious. For example grains and vegetable crops are plant materials but are much more valuable as food; and large, healthy trees are part of the total biomass, but lumber and wood products have the higher priority.

Feasibility exclusions generally are based on questions of as-received fuel value and preparability. For example, many land-based and aquatic plants with a favorable heat content in the dried state are received with such a high moisture content that neither "as-received" combustion nor pre-drying preparation are practical; and many vine-like, fibrous plants with otherwise lower moisture contents are incapable of being shredded or ground up into a suitable size for combustion fuel.

Biomass fuels are basically as follows:

- Bagasse – the residue (stalks) of cane-type plants from which the sugar and juices have been extracted.

- Wood Wastes – the bark, sawdust, shavings, trimmed or rotted parts.

- Forest Residue – wood left in the forest after logging.
- Husks – rice and other seed coverings.
- Nut Shells – covering protecting the nut meat.

Other contractors have prepared reviews dealing with other means of biomass utilization, and the definitions may differ to some extent, depending on the various processes, systems and end products of utilization. However, for the purposes of this review, biomass will be understood to mean only those types of plant materials suitable for combustion and which fit into one of the categories listed above.

The mechanical engineering aspects of the study use the following terms:

Ambient temperature – The temperature of the air surrounding the equipment.

Attemperator – An apparatus for reducing and controlling the temperature of a superheated vapor or fluid passing through it.

Auxiliary fuel – A fuel, of a different type than the fuel that is normally used to fire the boiler, which is introduced in order to bring the fire up to desired standards, or to supplement the primary fuel during shortages.

Base load – That minimum portion of a station or boiler load that is practically constant for long periods.

Blowdown – Removal of a portion of boiler water for the purpose of removal of sludge.

Busbar power cost – The switch yard power cost of the net power supplied by a generating plant.

Demineralizer – A device designed to remove dissolved minerals, metals and other chemicals from water.

Duct – Large diameter piping or rectangular conduit used to conduct gases.

Economizer – A device for transferring heat from flue gas to water and/or air on its way to the furnace.

Fire tube steam generator - A boiler with straight tubes, which are surrounded by water and steam and through which the products of combustion pass.

Flame-out - A loss of combustion in a furnace due to conditions which will no longer allow the fuel to burn.

Flue - A passage for products of combustion to the stack.

Flue gas - The gaseous products of combustion in the flue to the stack.

Forced Draft - Air, under pressure, to the fuel burning equipment.

Fuel fines - That portion of pulverized solid fuel which falls below the set lower size limits.

Full steam load capabilities - The steam producing capacity that the boiler was rated to achieve.

Induced draft - Draft created by a drop in pressure.

Low calorific, high volumineous fuel - Fuel with a low heat content to volume ratio.

Overfire air - Air for combustion admitted to the furnace at a point above the fuel bed.

Particulate carryover - A portion of char or ash particles suspended in the flue gas.

Pelletizing - The densifying of solid fuel (usually refuse) into pellets of uniform size and composition.

Process heat - Boiler heat used in the plant for purposes other than the generation of electricity.

Saturated steam - Steam at the temperature corresponding to its pressure.

Stack - A vertical conduit, which due to the difference in density between internal and external gases creates a draft at its base.

Stack gas - Gas arising as a product of combustion, in transit up through the stack from the flue.

Steaming rates - The steam production usually expressed in a weight of steam produced in a unit of time.

Superheated steam - Steam at a higher temperature than its saturation temperature.

Tuyeres - An opening through which air is introduced.

Water tube generator -- A boiler with water and steam filled tubes, surrounded by the products of combustion.

Wigwam burner - A large incinerator, conical in shape, made of closely woven heavy wire or sheet metal.

Some abbreviations used in the text are listed. Generally the names of scientists honored by society are capitalized in an abbreviation of a unit that bears their name.

Btu - British thermal unit

cfm - Cubic feet per minute

cm - Centimeter

da - Day

ft - Feet

hr - Hour

hp - Horsepower

in. w.g. - Inches of water as read from a water gage

^{o}K - Temperature in degrees Kelvin

k cal - 1,000 calories

kg - Kilogram

kPa - Kilo-Pascals

kW - Kilowatt (1,000 watts)

kWh - Kilowatt - hour

lb - Pound

m - Meter

min - Minute

mm - Millimeter

MW - Megawatt (1,000,000 watts)

MWg - Molecular weight of gas

pph - Pounds per hour

ppm - Parts per million

psi - Pounds per square inch

sf - Square feet

SG - Specific gravity

yr - Year

INTRODUCTION

This review addresses the current "state-of-the-art" in direct combustion systems for the utilization of biomass energy. It was prepared under commission to the U.S. Department of Agriculture - Forest Service (USDA/FS) in behalf of the Office of Energy in the Agency for International Development (AID/OE). The review places the greatest emphasis on the direct combustion technology which is most readily adaptable to the resources and needs of developing countries.

PURPOSE

Most of the less developed countries (LDC) need a development of energy technologies that will help free them from the consequences of rapidly rising oil prices. In addition to the high cost of imported oil, the actual availability of oil and other fossil fuels is becoming a very real problem. Many LDC's have neither petroleum nor coal reserves to tap for energy development and industrialization. However, some of these countries already possess an alternate energy resource in the form of existing biomass materials, i.e., forest-type growth and/or agricultural residues (see DEFINITIONS); others may not have an abundance of existing material but may have the potential for increased agricultural productivity to yield a greater amount. Given the raw biomass, the major remaining step is to convert it to a useful energy form. The form could be simply heat for drying processes, or steam for heating or mechanical/electrical uses.

The purpose of this review is to provide a comprehensive summary of both conventional and advanced systems involving direct combustion, with which the conversion of biomass to useful energy can be accomplished. As a result of the information presented in the review the LDC manager or planner may be better able to form a judgment as to which system is most applicable or appropriate to his particular needs.

SCOPE

The scope of the review is defined by, and limited to, the following activities:

- o An identification of "off-the-shelf", conventional and advanced, direct combustion systems and of some vendor sources outside the U.S. (indirect systems, such as biomass by-product combustion, are not included);
- o An estimation of the applicability of the respective systems to the appropriate sector(s) and of the specific sector economics;
- o An evaluation of the potential for in-country utilization of the combustion systems;
- o An evaluation of the constraints on the utilization of such systems within the less developed countries.
- o An examination of the environmental impacts due to use of such systems within the LDC's.
- o A consideration of the "front-end" systems for processing dried materials for combustion.

This state-of-the-art review is intended to follow the scope, as outlined above and a sufficient amount of pertinent and beneficial information on direct combustion of biomass will have been generated for LDC use. However, since it is known that other contractors are working on other parts of the AID project (other systems of biomass utilization), this review does not extend beyond the subject of direct combustion of biomass. In addition, it should be understood that the meaning of direct combustion in this review applies only to those systems whereby a usable energy product is provided, i.e., process heat, steam and/or mechanical power; it does not apply to systems with the sole purpose of eliminating unwanted biomass waste by means of combustion, e.g., "wigwam" or "teepee" burners and refuse or garbage incinerators.

PRINCIPALS OF COMBUSTION AND COMBUSTION REQUIREMENTS

The "3 T's" of combustion applies to all types of fuels. The "3 T's" are time, turbulance and temperature. The "3 T's" are different for each fuel and allowances must be made for the differences in the particular combustion application.

Combustion is often defined as the rapid chemical combination of oxygen with the combustible elements of a fuel. The combustible elements that we are primarily concerned with are carbon and hydrogen. The oxygen source for boiler furnaces is usually air. The amount of air can vary greatly between various types of fuels, therefore, the air conveying system design may change with respect to kinds of equipment, duct sizing and other controlling parameters. The amount of air will also vary according to the amount of carbon and hydrogen contained in the various fuels.

These fundamental physical laws are the basis for combustion calculations:

- Matter is neither created nor destroyed.
- The amount of energy entering a process must equal the amount of energy leaving the process.

With these two fundamentals in mind different fuels can be compared by preparing theoretical combustion calculations. Consider that pounds of fuel (F) combined with pounds of air (A) will always result in (F + A) pounds of resulting combustion products. In the same token, the sum of all energy into the combustion process (generally expressed in calories or Btu's) will always equal the energy leaving the process. This is why the heating value of fuels is usually expressed as kilogram-calories or Btus so that an energy balance can be made on a common basis. With these principles, combustion calculations can be made and evaluated to show the differences between coal, oil, natural gas, wood, baggasse, corn cobs, rice hulls, etc.

To make combustion calculations certain information items are required before proceeding to evaluate an existing power plant for combustion of biomass. These are:

- o Total weight and composition of the fuel presently burned (combusted).
- o Amount of excess air required for the efficient combustion of the present fuel.
- o The weight and composition of the proposed conversion fuel.
- o Amount of excess air required for the efficient combustion of the proposed fuel.

If two (or more) fuels are to be burned in combination, then calculations must be made for each individual fuel as a separate entity.

COMBUSTION THEORY:

The solid biomass fuels have their noncombustibles: moisture and ash; and their combustibles: the non-volatiles and the volatiles.

When a biomass material is burned, pyrolysis takes place prior to the actual primary combustion of the non-volatile components. The volatile components are vaporized and burned in a post-flame, gas-phase reaction largely by the secondary combustion air. Some typical primary reactions are:

$$C_6H_{10}O_2 \dashrightarrow CO + CO_2 + H_2O$$

$$C_5H_8O_2 \dashrightarrow CO + CO_2 + H_2O$$

Some typical secondary combustion reactions are:

$$H_2 + O_2 \dashrightarrow H_2O$$

$$C_x H_y + O_2 \dashrightarrow CO_2 + H_2O$$

$$CO + O_2 \dashrightarrow CO_2$$

Some chemical reactions in the two combustion zones take up heat but the most beneficial give off a net surplus of heat providing the energy desired from the process. The most notable energy producing reactions are:

$$C + O_2 \dashrightarrow CO_2 + 94 \frac{kcal}{mol\ C}$$

$$CH_4 + O_2 \dashrightarrow CO_2 + 2H_2O + 212.8 \frac{kcal}{mol\ CH_4}$$

$$2H + O_2 \dashrightarrow H_2O + 68.3 \frac{kcal}{mol\ H_2}$$

A convenient formula for expressing the heat available from a fuel is by the Dulong Formula.

$$HHV = 14544\ C + 62028 \left(H - \frac{O}{8}\right) + 4050\ S$$

The O in the equation is oxygen; the percentage of Carbon (C), Hydrogen (H) and Sulfur (S), are the decimal equivalents; and the Higher Heating Value (HHV) is expressed in the English system in British Thermal Units per pound of fuel. The metric equivalent may be expressed in kilogram-calories by multiplying both sides of the equation by 3.968. The term for sulfur is generally negligible because there is so little sulfur in most biomass.

The first problem in establishing the combustion reactant quantities is to establish the amount of air required to exactly satisfy the oxygen requirements of the combustion elements C, H and S.

The following equation is used to determine the stoichiometric dry air quantity per pound of fuel burned.

$$\text{Air} = 11.53\ C + 34.34\ \left(H_2 - \frac{O}{8}\right) + 4.295$$

Again the percentages of reacting elements by weight are expressed as decimal equivalents. The metric equivalent in kilograms may be obtained by multiplying both sides of the equation by 2.205.

Once the stoichiometric quantity of dry air is known, the rule of thumb "excess air equals the moisture content of the fuel" is applied. Woody biomass is generally burned at between 30% excess air and 50% excess air. The stoichiometric air quantities are multiplied by the percentage of excess air expressed as a decimal equivalent: 1.3 for 30%, 1.5 for 50%, etc.

The reactants that make up the combustion products are:

1. The combustion air plus excess air by weight.
2. The as-burned fuel weight.
3. The weight of moisture in the air.

When these reactants are expressed in weights per hour, the total weight of the combustion products, and stack gas, is known.

Another important aspect of the stack gas is the moisture content and specific gravity. The moisture content by weight is determined by analysis of the fuel. The moisture comes from these sources:

1. The moisture from water in the fuel.
2. The moisture from hydrogen in the fuel.
3. The moisture in the air used to burn the fuel.

The moisture in the fuel is determined in the proximate or ultimate analysis; if you know or assume the amount of fuel burned per hour, the quantity of water is known. The moisture from hydrogen is obtained by multiplying the percentage of hydrogen in the fuel burned times the amount of fuel burned per hour by 9. The moisture in air is usually assumed to be the ABMA standard of 1.3% of the total air requirement by weight.

The specific gravity of stack gas requires predicting or it may be obtained by analyzing the stack gases for percentages of O_2, CO_2, CO and N + A by volume in an orsat apparatus by wet chemical methods. The Peabody Gordon Piatt Chart, Figure 2-1 shows the relationship between Oxygen, CO_2 in the stack gas and Excess Air. Good combustion usually results in a relatively low concentration (less than 200 ppm) of CO, so it is neglected in the specific gravity calculations.

The molecular weight of the stack gas may be determined by formula. The apparent molecular weight of dry flue gas may be calculated in terms of grams/gram-mol lb/lb-mol by the or following when the volumetric percentages are expressed as decimals.

$$O_2 \times 32 + CO_2 \times 44.010 + A_2 \times 39.944 + N \times 28.016 = MW_g$$

The density of the dry flue gas at 0°C or 32°F may be found by dividing the apparent molecular weight by 22.41 liters/gram-mol or 358.7 cubic feet/pound-mol, respectively.

The $\frac{MW_g}{28.966}$ equals the specific gravity of the dry flue gas relative to that dry air under the same conditions of pressure and temperature.

Table 1 shows typical heating values of selected types of biomass. Tables 2 and 3 are typical of the chemical analyses of bagasse, softwoods and hardwoods.

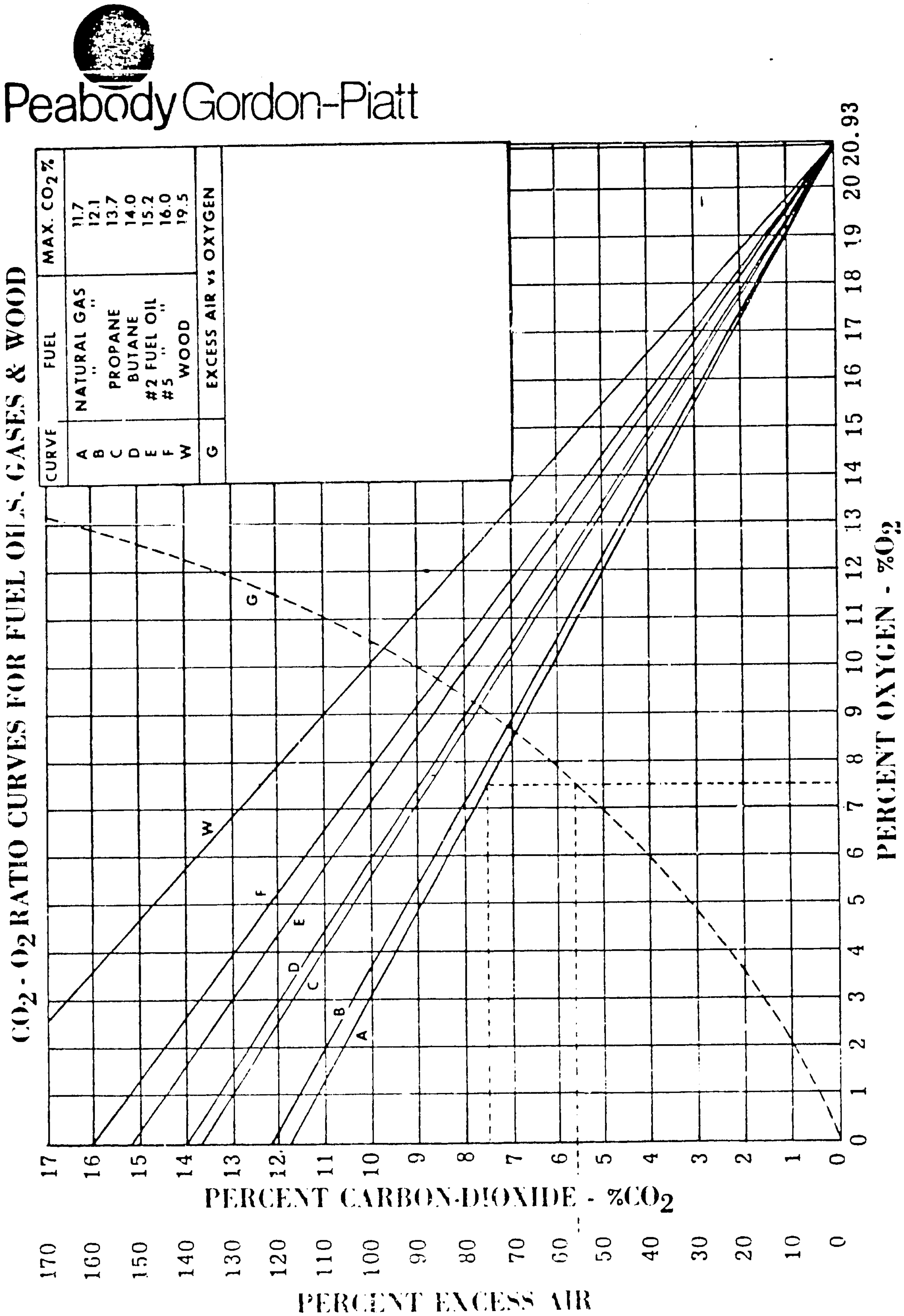

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Figure 2-1

TABLE 1
HEATING VALUES OF BIOMASS

Material	kcal/kg+	Btu/lb+
Latex (Coagulum)	10,950	19,700
Fir Bark	5,280	9,500
Redwood Hogfuel	4,910	8,840
Spruce Hogfuel	4,770	8,590
Cottonseed Hulls	4,780	8,600
Grain	3,960	7,130
Pecan Shells	4,500	8,100
Citrus Rinds	940*	1,700*
Corn Cobs	4,450	8,000
Coffee Grounds	5,560	10,000
Shelled Corn	4,750	8,550
Cotton, Unprocessed	3,630	6,540
Grass	3,930	7,070
Leaves	3,610	6,500
Brush	4,060	7,300
Rice Hulls	4,720	8,500

+ Naturally occuring state of materials (presumed to be partially dried)
* Heating value as fired presumed to be as received.

Table 2
TYPICAL ANALYSES OF BAGASSE

	Percent by Weight					Heating Value Btu per lb		Atmos. Air at Zero Excess Air lb per 10^6 Btu	CO_2 at Zero Excess Air, percent
	Carbon C	Hydrogen H_2	Oxygen O_2	Nitrogen N_2	Ash	Higher	Lower		
Cuba	43.15	6.00	47.95	—	2.90	7,985	7,402	625	21.0
Hawaii	46.20	6.40	45.90	—	1.50	8,160	7,538	687	20.3
Java	46.03	6.56	45.55	0.18	1.68	8,681	8,043	651	20.1
Mexico	47.30	6.08	35.30	—	11.32	9,140	8,548	667	19.4
Peru	49.00	5.89	43.36	—	1.75	8,380	7,807	699	20.5
Puerto Rico	44.21	6.31	47.72	0.41	1.35	8,386	7,773	625	20.5

Table 3
TYPICAL ANALYSIS OF DRY WOOD*

	Percent by Weight						Heating Value Btu per lb		Atmos. Air at Zero Excess Air lb/10^6 Btu	CO_2 at Zero Excess Air Percent
	Carbon C	Hydrogen H_2	Sulfur S	Oxygen O_2	Nitrogen N_2	Ash	High	Low		
SOFTWOODS										
Cedar, white	48.80	6.37	—	44.46	—	0.37	8,400*	7,780	709	20.2
Cypress	54.98	6.54	—	38.08	—	0.40	9,870*	9,234	711	19.5
Fir, Douglas	52.3	6.3	—	40.5	0.1	0.8	9,050	8,438	720	19.9
Hemlock, western	50.4	5.8	0.1	41.4	0.1	2.2	8,620	8,056	706	20.4
Pine, pitch	59.00	7.19	—	32.68	—	1.13	11,320*	10,620	702	18.7
white	52.55	6.08	—	41.25	—	0.12	8,900*	8,308	723	20.2
yellow	52.60	7.02	—	40.07	—	0.31	9,610*	8,927	710	19.3
Redwood	53.5	5.9	—	40.3	0.1	0.2	9,040	8,498	722	20.2
HARDWOODS										
Ash, white	49.73	6.93	—	43.04	—	0.30	8,920*	8,246	709	19.6
Beech	51.64	6.26	—	41.45	—	0.65	8,760*	8,151	729	20.0
Birch, white	49.77	6.49	—	43.45	—	0.29	8,650*	8,019	712	20.0
Elm	50.35	6.57	—	42.34	—	0.74	8,810*	8,171	715	19.8
Hickory	49.67	6.49	—	43.11	—	0.73	8,670*	8,039	711	20.0
Maple	5[illegible].64	6.02	—	41.74	0.25	1.35	8,580	7,995	719	20.2
Oak, black	48.78	6.09	—	44.98	—	0.15	8,180*	7,587	714	20.5
red	49.49	6.62	—	43.74	—	0.15	8,690*	8,037	709	19.9
white	50.44	6.59	—	42.73	—	0.24	8,810*	8,169	715	19.8
Poplar	51.64	6.26	—	41.45	—	0.65	8,920*	8,311	716	20.0

* Calculated from reported high heating value of kiln-dried wood assumed to contain 8 percent moisture.

In order to better understand the combustion theory and evaluate the combustion of various biomass fuels with fossil fuels five examples of combustion calculations follow.

These examples of combustion calculations for biomass and fossil fuels were prepared assuming the pressure is at sea level and the air contains 0.13 kg of water per kg of dry air or .013 lbs of water per lb of dry air. The analysis of fuel as fired is shown for each fuel used in the examples. The fossil fuel examples are shown to develop the theoretical air quantities for complete combustion with a biomass fuel. See Sample Biomass Combustion Calculations in Table 4.

The specific gravity of the flue gas can be divided by the density of air at any condition of temperature or pressure and multiplied by the weight of flue gas to obtain the actual gas volumes for the boiler exit and back end equipment conditions.

Volume of flue gas/min = $\frac{S_g \times W_x\ t_1 \times P_1}{d_a \times t_o \times P_o \times 60}$ in which S_g is the specific gravity of the flue gas per hour in kilograms, t_1 is the flue gas temperature in degrees Kelvin, and P_1 is the flue gas pressure in centimeters of water, d_a is the density in cubic meters per kilogram at

TABLE 4

SAMPLE BIOMASS COMBUSTION CALCULATIONS

Rice Husk Annual Production 50,000,000 kg/yr

$$\text{Use Rate} = \frac{50,000,000}{350 \text{ da/yr} \times 24 \text{ hr/da}} = 5952.38 \text{ kg/hr}$$

Ultimate Analysis:

Ash	=	19.13%	Nitrogen	=	0.46%
Moisture	=	5.72%	Sulfur	=	.07%
Carbon	=	39.71%	Oxygen	=	29.90%
Hydrogen	=	5.01%	Total	=	100.00%

HHV = 3542 kcal/kg

30% Excess Air

5952.38 x 5.018 x 1.3 = 38,834.4 kg/hr

Flue Gas Weights

Weight of combustion air	=	38,834.4 kg/hr
Weight of fuel	=	5,952.4 kg/hr
H_2O in air (.013 x 38,834.4)	=	504.8 kg/hr
Weight of flue gas	=	45,291.6 kg/hr

Moisture in Flue Gas

Fuel moisture (.0572 x 5952.38)	=	340.43 kg
Moisture from H_2 (9 x .0501 x 5952.38)	=	2683.93 kg
Moisture in air (.013 x 38,834.4)	=	504.85 kg
Weight of moisture in Flue Gas	=	3529.26 kg

$$\text{Percent moisture} = \frac{3529.26}{45291.6} = 7.8\%$$

Stoichiometric Air

$$SA = 11.53\,C + 34.34\,(H - \frac{O}{8} \quad 4.29\,S$$

$$= 4.578 + .4370 + .0030$$

$$= 5.0186 \text{ kg air/kg fuel}$$

Molecular Weight of Dry Flue Gas from PGP Chart

O_2	=	4.9%	N_2	=	100 - 20.7
CO_2	=	14.8%	N_2	=	79.4
A	$\sim$	1.0%			
Subtotal		20.7%			

$$MWg = .049(32) + .148(44.01) + .010(39.944) + .794(28.016) = 30.73 \text{ kg/kg mol.}$$

Specific Gravity of Flue Gas (Relative to Air)

$$SG = \frac{(100 - 7.79)\ 30.69}{100 \times 28.966} + \frac{7.79 \times 18.016}{100 \times 28.966}$$

SG = .977 + .048 = 1.025 times that of air

273.15°K. t_o is the standard temperature 273.15°k, and P_o is the standard atmospheric pressure at 1033.25 cm of water.

Since most biomass fuel will be accompanied by some auxiliary fuel, sample calculations for obtaining the theoretical air requirements are given in Table 5 for a coal, in Table 6 for an oil, Table 7 for a natural gas and Table 8 for a dry, suspension-fired wood dust.

Table 5

SAMPLE COAL CALCULATIONS FOR THEORETICAL AIR

Ultimate Analysis

wt/wt of fuel as fired	Divisor	Moles of O_2	Multiplier	Moles of N_2
C = .720	12	.0600		
H_2= .044	4	.0110		
O_2= .036	-32	(- .0011)		
N_2= .014	28	-		.0005
S = .016	32	.0005		
H_2O = .080	-	-		
Ash = .090	-	-		
Sum = 1.000	Moles O_2 required =	.0704	3.76	.2647
			Moles of N_2 =	.2652

Moles of dry air = O_2 + N_2 = .0704 + .2652 = .3356

Weight of dry air = .3356 x 28.966 = 9.7210
(as kg of air/kg of fuel or lb of air/lb of fuel)

Weight of wet air = (9.721)+.013 (moisture) = 9.8474

Theoretical air = 9.8474 kgs air/kg fuel or lbs air/lb fuel

Table 6

SAMPLE BUNKER C OIL CALCULATIONS FOR THEORETICAL AIR

Ultimate Analysis wt/wt of fuel as fired			Divisor	Moles of O_2	Multiplier		Moles of N_2
C	=	.879	12	.0733			
H_2	=	.103	4	.0258			
S	=	.012	32	.0004			
O_2	=	.005	-32	(-.0002)			
N_2	=	.001	28	-			-
Sum	=	1.000	Moles O_2 required =	.0993	3.76	=	.3734
					Moles of N_2	=	.3734

Moles of dry air = O_2 + N_2 = .0993 + .3734 = .4727

Weight of dry air = .4727 x 28.966 = 13.6922
as kgs of air/kg of fuel or lbs of air/lb of fuel

Weight of wet air = (13.6922) 1+.013 (moisture) = 13.8702

Theoretical air = 13.8702 kgs air/kg fuel or lbs air/lb fuel

Table 7

SAMPLE NATURAL GAS CALCULATIONS FOR THEORETICAL AIR
(volumetric analyses 1 liter)

Volumetric Analyses	Multipliers for $C+\frac{H}{4}$	Liters of O_2	Multiplier for N	Liters of N_2*
CH_4 = .853	1 + 1	1.706		
C_2H_6 = .126	2 + 1-1/2	.441		
O_2 = .003		(-.003)		
N_2 = .017				.017
CO_2 = .001				.001
Sum = 1.000	liter O_2 =	2.144	3.76	8.061
			liters of N_2 =	8.079*

Liters of dry air = O_2 + N_2* = 2.144 + 8.079 = 10.223

Liters per gram-mole @ 20°C = $22.412 \times \frac{293}{273}$ = 24.054

Weight of dry air = $\frac{10.223}{24.054} \times 28.966$ = 12.311g

grams of air/gram of fuel or lbs of air/lb of fuel

Weight of wet air = (12.311)1+.013 moisture = 12.471

Theoretical air = 12.471 kg air/kg fuel or lbs air/lb fuel

* CO_2 in original gas

Table 8

SAMPLE DRY WOOD DUST CALCULATIONS FOR THEORETICAL AIR

Ultimate Analysis of Dry Wood		Divisor	Moles O_2		Multiplier		Moles N_2
C =	.5010	12	.0418				
H_2 =	.0634	4	.0159				
O_2 =	.4173	-32	(-.0130)				
S =	.0002	32	-				
N_2 =	.0032	-	-				.0032
Ash =	.0159	-	-				-
Sum =	1.0000	Moles O_2 =	.0447	x	3.76	=	.1681
					Moles N_2	=	.1713

Moles of dry air = O_2 + N_2 = .0447 + .1713 = .2160

Weight of dry air = .2160 x 28.966 = 6.2567
(in kgs of air/kg of fuel or lbs of air/lb of fuel)

Weight of wet air = 6.2567 (1+.013) = 6.3380

Theoretical air = 6.338 kgs fuel/kg air or lbs fuel/lb air

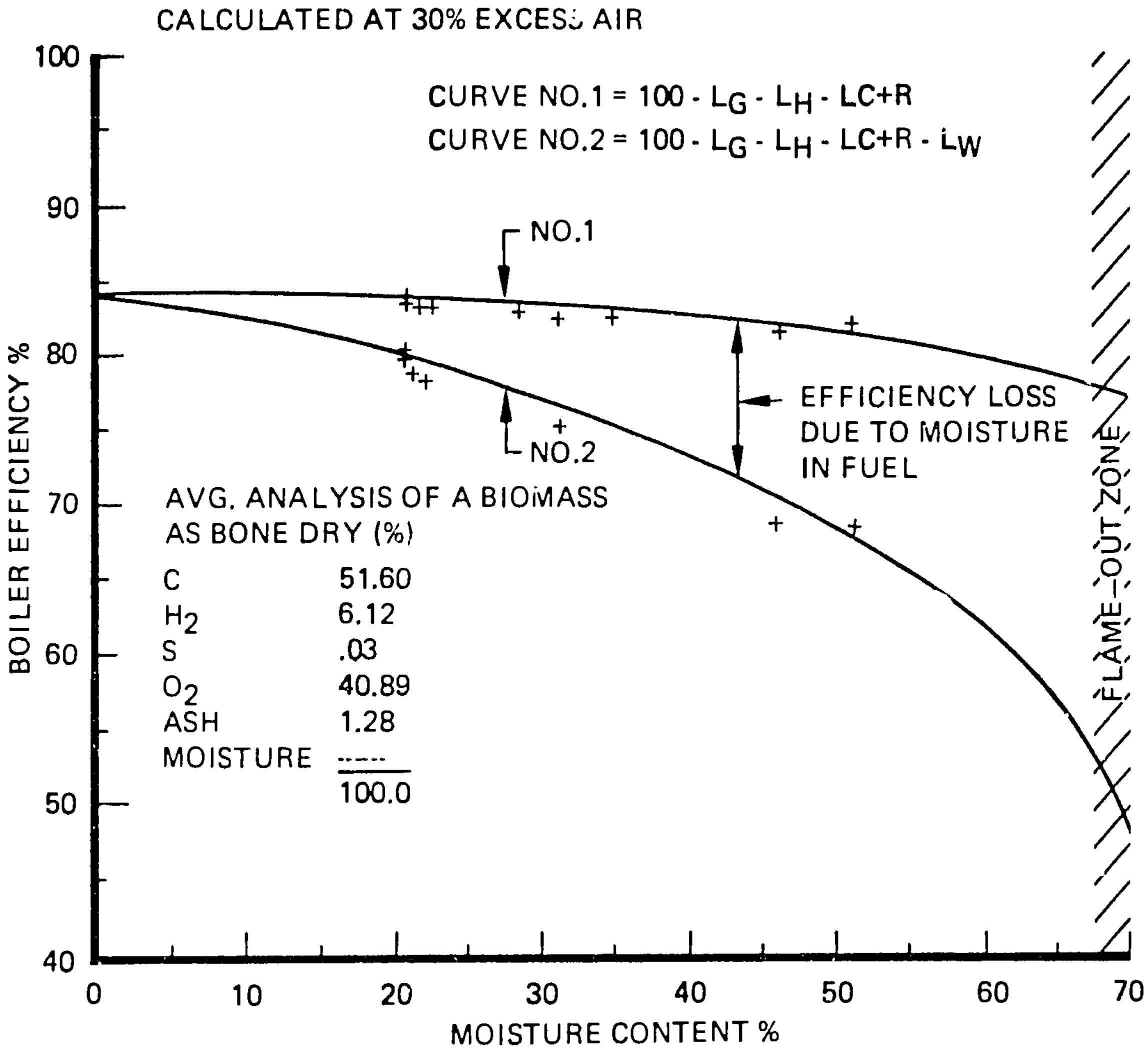
Where more than one fuel is burned simultaneously, the total air requirement is the summation of the theoretical and excess air requirements of each fuel component. Generally, the slower burning of the biomass fuels is "base loaded" and its air requirement is adjusted to sustain its combustion. The other fuels are more easily fed to meet the varying heat requirements of the system so their air requirements are controlled to pace the rate of auxiliary fuel being fired. The designer may select several different fuels that can be fired in this manner.

As previously mentioned, moisture in the fuel will greatly influence net heat output of a boiler. Heat is necessary to evaporate the moisture from the fuel and this heat for evaporation comes from the fuel itself, and therefore, reduces the boilers ability to put heat into the final steam end product. As will be seen later, this factor has a major effect on furnace and boiler design. The evaporated fuel moisture also takes up space in the furnace reducing the residence time of the hot combustion products in the boiler. Both factors reduce boiler operating efficiency.

Losses make up a large portion of the heat balance in combustion calculations. Unburned carbon, CO gas in lieu of CO_2 and heat lost up the stack constitute the majority of these losses. Radiation and external convection losses are normally controlled by design and insulation, and therefore, account for a very small part of the losses in the heat balance. Unburned carbon and combustion of CO gas can be recovered to produce useful heat by special design considerations in the fuel firing equipment. These considerations may impact the furnace design, the fuel feeding equipment and the fuel moisture content and size of the fuel that is fired.

Babcock and Wilcox, a large boiler manufacturer, has stated that the greatest heat loss is the loss up the stack. Since the heat in the fuel is determined from a base of ambient temperature, all the products of combustion must be cooled to this temperature if all the heat is to be utilized. Higher exhaust temperatures then represent a loss, which is the sum of four items: (1) The sensible heat in the dry combustion products, (2) the sensible heat in the moisture that was in the air, (3) the sensible heat in both the water from combustion and the moisture content in the fuel and (4) the latent heat of the moisture content in the fuel. The importance of moisture in combustion efficiency should not be underestimated. See Figure 2-2 for an example that shows the drop in boiler efficiency that occurs when wet wood is burned. Flame out occurs

LOSSES AFFECTING BOILER EFFICIENCY
METHOD USED: ASME PTC 4.1-b



BE =BOILER EFFICIENCY = 100 - (L_G+L_H+L_{C+R}+L_W)

L_G =HEAT LOSS DUE TO DRY GAS $= \frac{W_G \times SP.\ HT \times (t_2 - t_1) \times 100}{HHV}$

W_G =WEIGHT OF STACK GAS/LB. OF FUEL

SP. HT =SPECIFIC HEAT (0.24)

t_1 =TEMPERATURE OF INCOMING AIR 70°F

t_2 =TEMPERATURE OF STACK GAS 400°F

HHV =HEAT VALUE AS RECEIVED IN BTU/LB

L_W =HEAT LOSS DUE TO MOISTURE (%)

L_H =HEAT LOSS DUE TO H_2O FROM COMBUSTION OF H_2 (%)

L_{C+R} =HEAT LOSSES DUE TO COMBUSTIBLE IN REFUSE AND RADIATION (%)

29033-89

Figure 2-2

at about 68% moisture when calculated on a wet (as received) basis.

Table 9 shows the suggested range of excess air required for various types of fuel-burning equipment. Note that there is a wide variation for any given fuel which is dependent on the configuration, air duct capacities, grate openings and many other aspects of the design of the fuel burning equipment. This fact is extremely important when considering a conversion from one fuel to another and what modifications must occur.

Table 9

EXCESS AIR AT FURNACE OUTLET

	Fuel	Excess air in %
Solid fuels	Coal	10-40
	Coke	20-40
	Wood	25-40
	Bagasse	25-45
Liquid fuels	Oil	3-15
Gaseous fuels	Natural gas	5-10
	Refinery gas	8-15
	Blast furnace gas	15-25
	Coke oven gas	5-10

COMBUSTION SYSTEMS APPLICATIONS

The direct combustion of biomass for the production of heat energy can be divided into four basic system groups. The distinct groups, in an approximate order of increasing technology, are as follows:

- o Pile Burning
- o Stoker Fired Grate Burning
- o Suspension Burning
- o Fluidized Bed

These groups can be distinguished essentially by understanding the relative differences in the ways which the fuel is burned. The name of each group reveals something of the intrinsic characteristics of each system. Pile burning does, for example, make use of an actual pile of fuel with which to maintain the combustion process. Bark and slabs of wood can be ground up and fired by a spreader-stoker device over a grate. Grate burning involves the use of a grate through or over which spent ash is separated from the incoming fuel. Suspension burning can eliminate the need for a grate, in that the fine fuel particles are burned in suspension with air, much like an oil or natural gas combustion flame. Fluidized bed technology allows the fuel to burn in a floating and agitated "bed" mixture of fuel and noncombustible mineral.

Each method has its own advantages and disadvantages in comparison to the others, but the actual judgment of what is an advantage or disadvantage is most often a matter of careful consideration of the particular place and situation in which the system is to be used. Advanced systems which were developed for their advantages in efficiency and/or fuel and ash handling capabilities near a highly industrialized center may be completely inappropriate in a less developed location. Nevertheless, in the interest of showing the full range of technology which is currently available, all four combustion methods are included for review.

Pile Burning

The three systems available for pile burning are the Dutch oven, cyclonic and fuel cell types.

Dutch Oven

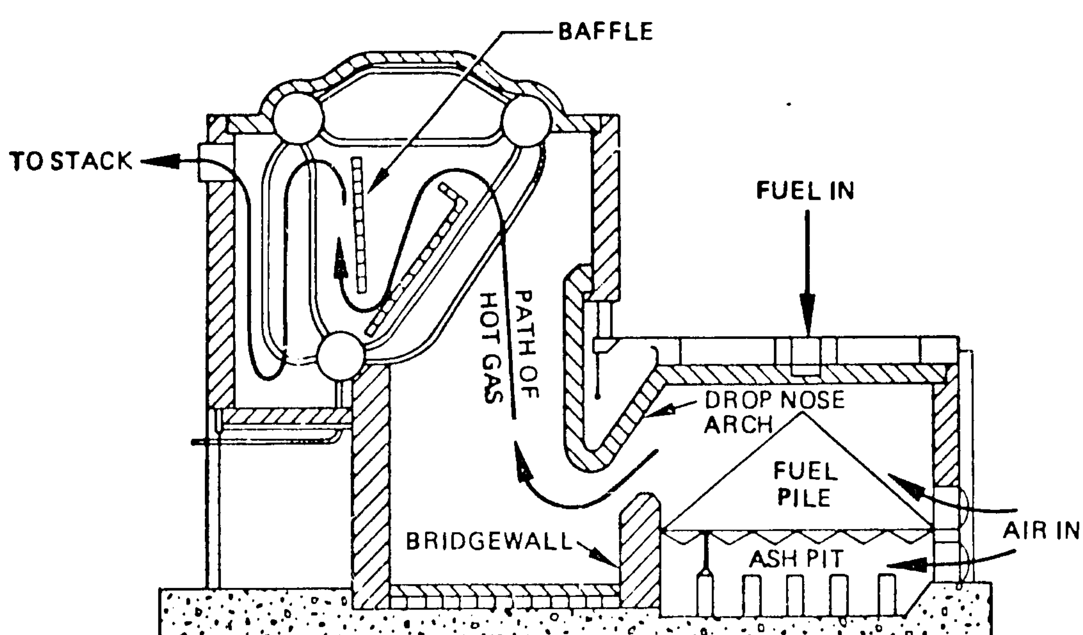
Of all the systems of combustion now available, the Dutch oven is probably the oldest still in use. This pile burning system has seen long use in the forest product and sugar industries, in particular.

The standard Dutch-oven installation is a two-cell furnace built up of heavy refractory walls with a grate in the bottom and tuyeres in the walls through which combustion air is supplied. Fuel is introduced into the furnace through openings in the walls or the roof to form a conical pile on the grate. Drying of the fuel, along with gasification, takes place in the first compartment, and the combustion of the gases produced from the volatile matter occurs in the second compartment. Because pile burning is mostly a matter of surface combustion the use of refractory arches and walls in the first chamber is essential. These refractory surfaces provide the maximum amount of radiant and reflected heat for maintaining evaporation and gasification. They are also important in preventing the fire from being smothered with new fuel dropping on the surface of the pile.

The size and shape of the cells depends on many variables. Type of biomass, moisture content, pretreatment of fuel, number of fuel openings, use of preheated combustion air, etc. all influence the design. For example, since a high moisture content fuel would require more radiation from the arch, overfire air must be more thoroughly mixed with the gas and the velocity of the gas through the furnace must be slower. However, the characteristics of the Dutch oven are such that they can be designed for many types of fuel and, with some compromise in design, variations in a given fuel composition can be accommodated. It is desirable that the maximum size of the fuel be limited, accomplished by passing the fuel through a hog or grinder, and that the moisture content be fairly uniform.

Dutch ovens may be fitted with steam generators ranging from fire-tube boilers generating saturated steam at 1730 kPa (250 psi) to water-tube units producing superheated steam. Because of size restrictions, however, steaming rates have an upper limit. To achieve greater steam production, two or more cells may be installed under a boiler. Figure 2-3 shows a boiler with a dutch-oven furnace.

BOILER WITH A DUTCH-OVEN FURNACE



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ABSTRACT

A review of the current state-of-the-art in direct combustion systems of biomass residues is directed to developing countries. "Off-the-shelf" conventional direct combustion systems are identified and vendor sources listed. The economics of in-country utilization of direct combustion systems are discussed. Constraints and applicability of the respective systems are reviewed along with an examination of the environmental problems associated with them.

Principals of biomass combustion, tables of biomass analyses for use as fuels and sample combustion calculations are given.

Handling and processing of biomass materials including drying to aid combustion is discussed. Material vendors of equipment needed to handle biomass materials are listed.

The appendix lists equipment manufacturers with addresses of their world wide agents.

Biomass fueled electric power plant advantages and disadvantages are discussed and as well as costs associated with a typical 16 mega Watt electric biomass fueled plant producing 50% cogenerated steam.

ACKNOWLEDGEMENTS

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DIRECT COMBUSTION OF BIOMASS

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DEFINITIONS AND ABBREVIATIONS

Generally speaking, the word "biomass" applies to virtually all types of plant growth material, whether it grows on land or within lakes and oceans. However, much of what is loosely referred to as biomass is not suitable for energy conversion by combustion.

The reasons for rejection of numerous plant materials as combustion fuel usually fall into one of two categories: value priority and preparation feasibility. Priority exclusions are often obvious. For example, grains and vegetable crops are plant materials but are much more valuable as food; and large, healthy trees are part of the total biomass, but lumber and wood products have the higher priority.

Feasibility exclusions generally are based on questions of as-received fuel value and preparability. For example, many land-based and aquatic plants with a favorable heat content in the dried state are received with such a high moisture content that neither "as-received" combustion nor pre-drying preparation are practical; and many vine-like, fibrous plants with otherwise lower moisture contents are incapable of being shredded or ground up into a suitable size for combustion fuel.

Biomass fuels are basically as follows:

- o Bagasse - the residue (stalks) of cane-type plants from which the sugar and juices have been extracted.

- o Wood Wastes - the bark, sawdust, shavings, trimmed or rotted parts.

- o Forest Residue – wood left in the forest after logging.
- o Husks – rice and other seed coverings.
- o Nut Shells – covering protecting the nut meat.

Other contractors have prepared reviews dealing with other means of biomass utilization, and the definitions may differ to some extent, depending on the various processes, systems and end products of utilization. However, for the purposes of this review, biomass will be understood to mean only those types of plant materials suitable for combustion and which fit into one of the categories listed above.

The mechanical engineering aspects of the study use the following terms:

Ambient temperature – The temperature of the air surrounding the equipment.

Attemperator – An apparatus for reducing and controlling the temperature of a superheated vapor or fluid passing through it.

Auxiliary fuel – A fuel, of a different type than the fuel that is normally used to fire the boiler, which is introduced in order to bring the fire up to desired standards, or to supplement the primary fuel during shortages.

Base load – That minimum portion of a station or boiler load that is practically constant for long periods.

Blowdown – Removal of a portion of boiler water for the purpose of removal of sludge.

Busbar power cost – The switch yard power cost of the net power supplied by a generating plant.

Demineralizer – A device designed to remove dissolved minerals, metals and other chemicals from water.

Duct – Large diameter piping or rectangular conduit used to conduct gases.

Economizer – A device for transferring heat from flue gas to water and/or air on its way to the furnace.

Fire tube steam generator - A boiler with straight tubes, which are surrounded by water and steam and through which the products of combustion pass.

Flame-out - A loss of combustion in a furnace due to conditions which will no longer allow the fuel to burn.

Flue - A passage for products of combustion to the stack.

Flue gas - The gaseous products of combustion in the flue to the stack.

Forced Draft - Air, under pressure, to the fuel burning equipment.

Fuel fines - That portion of pulverized solid fuel which falls below the set lower size limits.

Full steam load capabilities - The steam producing capacity that the boiler was rated to achieve.

Induced draft - Draft created by a drop in pressure.

Low calorific, high volumineous fuel - Fuel with a low heat content to volume ratio.

Overfire air - Air for combustion admitted to the furnace at a point above the fuel bed.

Particulate carryover - A portion of char or ash particles suspended in the flue gas.

Pelletizing - The densifying of solid fuel (usually refuse) into pellets of uniform size and composition.

Process heat - Boiler heat used in the plant for purposes other than the generation of electricity.

Saturated steam - Steam at the temperature corresponding to its pressure.

Stack - A vertical conduit, which due to the difference in density between internal and external gases creates a draft at its base.

Stack gas - Gas arising as a product of combustion, in transit up through the stack from the flue.

Steaming rates - The steam production usually expressed in a weight of steam produced in a unit of time.

Superheated steam - Steam at a higher temperature than its saturation temperature.

Tuyeres - An opening through which air is introduced.

Water tube generator - A boiler with water and steam filled tubes, surrounded by the products of combustion.

Wigwam burner - A large incinerator, conical in shape, made of closely woven heavy wire or sheet metal.

Some abbreviations used in the text are listed. Generally the names of scientists honored by society are capitalized in an abbreviation of a unit that bears their name.

Btu - British thermal unit

cfm - Cubic feet per minute

cm - Centimeter

da - Day

ft - Feet

hr - Hour

hp - Horsepower

in. w.g. - Inches of water as read from a water gage

°K - Temperature in degrees Kelvin

k cal - 1,000 calories

kg - Kilogram

kPa - Kilo-Pascals

kW - Kilowatt (1,000 watts)

kWh - Kilowatt - hour

lb - Pound

m - Meter

min - Minute

mm - Millimeter

MW - Megawatt (1,000,000 watts)

MWg - Molecular weight of gas

pph - Pounds per hour

ppm - Parts per million

psi - Pounds per square inch

sf - Square feet

SG - Specific gravity

yr - Year

INTRODUCTION

This review addresses the current "state-of-the-art" in direct combustion systems for the utilization of biomass energy. It was prepared under commission to the U.S. Department of Agriculture - Forest Service (USDA/FS) in behalf of the Office of Energy in the Agency for International Development (AID/OE). The review places the greatest emphasis on the direct combustion technology which is most readily adaptable to the resources and needs of developing countries.

PURPOSE

Most of the less developed countries (LDC) need a development of energy technologies that will help free them from the consequences of rapidly rising oil prices. In addition to the high cost of imported oil, the actual availability of oil and other fossil fuels is becoming a very real problem. Many LDC's have neither petroleum nor coal reserves to tap for energy development and industrialization. However, some of these countries already possess an alternate energy resource in the form of existing biomass materials, i.e., forest-type growth and/or agricultural residues (see DEFINITIONS); others may not have an abundance of existing material but may have the potential for increased agricultural productivity to yield a greater amount. Given the raw biomass, the major remaining step is to convert it to a useful energy form. The form could be simply heat for drying processes, or steam for heating or mechanical/electrical uses.

The purpose of this review is to provide a comprehensive summary of both conventional and advanced systems involving direct combustion, with which the conversion of biomass to useful energy can be accomplished. As a result of the information presented in the review the LDC manager or planner may be better able to form a judgment as to which system is most applicable or appropriate to his particular needs.

SCOPE

The scope of the review is defined by, and limited to, the following activities:

- An identification of "off-the-shelf", conventional and advanced, direct combustion systems and of some vendor sources outside the U.S. (indirect systems, such as biomass by-product combustion, are not included);

- An estimation of the applicability of the respective systems to the appropriate sector(s) and of the specific sector economics;

- An evaluation of the potential for in-country utilization of the combustion systems;

- An evaluation of the constraints on the utilization of such systems within the less developed countries.

- An examination of the environmental impacts due to use of such systems within the LDC's.

- A consideration of the "front-end" systems for processing dried materials for combustion.

This state-of-the-art review is intended to follow the scope, as outlined above and a sufficient amount of pertinent and beneficial information on direct combustion of biomass will have been generated for LDC use. However, since it is known that other contractors are working on other parts of the AID project (other systems of biomass utilization), this review does not extend beyond the subject of direct combustion of biomass. In addition, it should be understood that the meaning of direct combustion in this review applies only to those systems whereby a usable energy product is provided, i.e., process heat, steam and/or mechanical power; it does not apply to systems with the sole purpose of eliminating unwanted biomass waste by means of combustion, e.g., "wigwam" or "teepee" burners and refuse or garbage incinerators.

PRINCIPALS OF COMBUSTION AND COMBUSTION REQUIREMENTS

The "3 T's" of combustion applies to all types of fuels. The "3 T's" are time, turbulance and temperature. The "3 T's" are different for each fuel and allowances must be made for the differences in the particular combustion application.

Combustion is often defined as the rapid chemical combination of oxygen with the combustible elements of a fuel. The combustible elements that we are primarily concerned with are carbon and hydrogen. The oxygen source for boiler furnaces is usually air. The amount of air can vary greatly between various types of fuels, therefore, the air conveying system design may change with respect to kinds of equipment, duct sizing and other controlling parameters. The amount of air will also vary according to the amount of carbon and hydrogen contained in the various fuels.

These fundamental physical laws are the basis for combustion calculations:

- o Matter is neither created nor destroyed.
- o The amount of energy entering a process must equal the amount of energy leaving the process.

With these two fundamentals in mind different fuels can be compared by preparing theoretical combustion calculations. Consider that pounds of fuel (F) combined with pounds of air (A) will always result in (F + A) pounds of resulting combustion products. In the same token, the sum of all energy into the combustion process (generally expressed in calories or Btu's) will always equal the energy leaving the process. This is why the heating value of fuels is usually expressed as kilogram-calories or Btus so that an energy balance can be made on a common basis. With these principles, combustion calculations can be made and evaluated to show the differences between coal, oil, natural gas, wood, baggasse, corn cobs, rice hulls, etc.

To make combustion calculations certain information items are required before proceeding to evaluate an existing power plant for combustion of biomass. These are:

- o Total weight and composition of the fuel presently burned (combusted).
- o Amount of excess air required for the efficient combustion of the present fuel.
- o The weight and composition of the proposed conversion fuel.
- o Amount of excess air required for the efficient combustion of the proposed fuel.

If two (or more) fuels are to be burned in combination, then calculations must be made for each individual fuel as a separate entity.

COMBUSTION THEORY:

The solid biomass fuels have their noncombustibles: moisture and ash; and their combustibles: the non-volatiles and the volatiles.

When a biomass material is burned, pyrolysis takes place prior to the actual primary combustion of the non-volatile components. The volatile components are vaporized and burned in a post-flame, gas-phase reaction largely by the secondary combustion air. Some typical primary reactions are:

$$C_6H_{10}O_2 \longrightarrow CO + CO_2 + H_2O$$

$$C_5H_8O_2 \longrightarrow CO + CO_2 + H_2O$$

Some typical secondary combustion reactions are:

$$H2 + O_2 \dashrightarrow H_2O$$

$$C_x H_y + O_2 \dashrightarrow CO_2 + H_2O$$

$$CO + O_2 \dashrightarrow CO_2$$

Some chemical reactions in the two combustion zones take up heat but the most beneficial give off a net surplus of heat providing the energy desired from the process. The most notable energy producing reactions are:

$$C + O_2 \dashrightarrow CO_2 + 94 \frac{kcal}{mol\ C}$$

$$CH_4 + O2 \dashrightarrow CO_2 + 2H_2O + 212.8 \frac{kcal}{mol\ CH_4}$$

$$2H + O_2 \dashrightarrow H_2O + 68.3 \frac{kcal}{mol\ H_2}$$

A convenient formula for expressing the heat available from a fuel is by the Dulong Formula.

$$HHV = 14544\ C + 62028\ \left(H - \frac{O}{8}\right) + 4050\ S$$

The O in the equation is oxygen; the percentage of Carbon (C), Hydrogen (H) and Sulfur (S), are the decimal equivalents; and the Higher Heating Value (HHV) is expressed in the English system in British Thermal Units per pound of fuel. The metric equivalent may be expressed in kilogram-calories by multiplying both sides of the equation by 3.968. The term for sulfur is generally negligible because there is so little sulfur in most biomass.

The first problem in establishing the combustion reactant quantities is to establish the amount of air required to exactly satisfy the oxygen requirements of the combustion elements C, H and S.

The following equation is used to determine the stoichiometric dry air quantity per pound of fuel burned.

$$\text{Air} = 11.53\ C + 34.34\ \left(H_2 - \frac{O}{8}\right) + 4.295$$

Again the percentages of reacting elements by weight are expressed as decimal equivalents. The metric equivalent in kilograms may be obtained by multiplying both sides of the equation by 2.205.

Once the stoichiometric quantity of dry air is known, the rule of thumb "excess air equals the moisture content of the fuel" is applied. Woody biomass is generally burned at between 30% excess air and 50% excess air. The stoichiometric air quantities are multiplied by the percentage of excess air expressed as a decimal equivalent: 1.3 for 30%, 1.5 for 50%, etc.

The reactants that make up the combustion products are:

1. The combustion air plus excess air by weight.
2. The as-burned fuel weight.
3. The weight of moisture in the air.

When these reactants are expressed in weights per hour, the total weight of the combustion products, and stack gas, is known.

Another important aspect of the stack gas is the moisture content and specific gravity. The moisture content by weight is determined by analysis of the fuel. The moisture comes from these sources:

1. The moisture from water in the fuel.
2. The moisture from hydrogen in the fuel.
3. The moisture in the air used to burn the fuel.

The moisture in the fuel is determined in the proximate or ultimate analysis; if you know or assume the amount of fuel burned per hour, the quantity of water is known. The moisture from hydrogen is obtained by multiplying the percentage of hydrogen in the fuel burned times the amount of fuel burned per hour by 9. The moisture in air is usually assumed to be the ABMA standard of 1.3% of the total air requirement by weight.

The specific gravity of stack gas requires predicting or it may be obtained by analyzing the stack gases for percentages of O_2, CO_2, CO and N + A by volume in an orsat apparatus by wet chemical methods. The Peabody Gordon Piatt Chart, Figure 2-1 shows the relationship between Oxygen, CO_2 in the stack gas and Excess Air. Good combustion usually results in a relatively low concentration (less than 200 ppm) of CO, so it is neglected in the specific gravity calculations.

The molecular weight of the stack gas may be determined by formula. The apparent molecular weight of dry flue gas may be calculated in terms of grams/gram-mol lb/lb-mol by the or following when the volumetric percentages are expressed as decimals.

$$O_2 \times 32 + CO_2 \times 44.010 + A_2 \times 39.944 + N \times 28.016 = MW_g$$

The density of the dry flue gas at $0^{o}C$ or $32^{o}F$ may be found by dividing the apparent molecular weight by 22.41 liters/gram-mol or 358.7 cubic feet/pound-mol, respectively.

The $\frac{MW_g}{28.966}$ equals the specific gravity of the dry flue gas relative to that dry air under the same conditions of pressure and temperature.

Table 1 shows typical heating values of selected types of biomass. Tables 2 and 3 are typical of the chemical analyses of bagasse, softwoods and hardwoods.

Peabody Gordon-Piatt

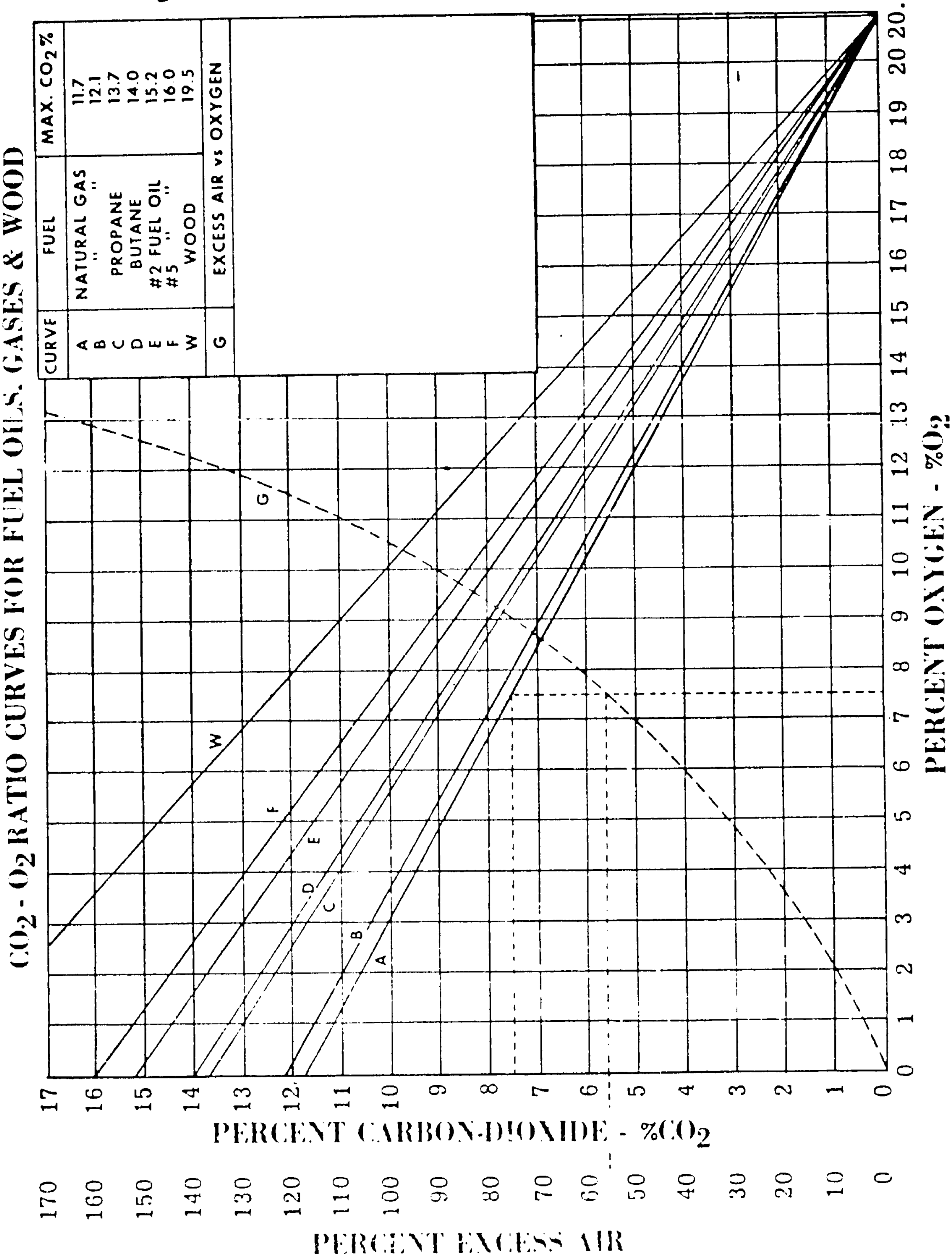

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Figure 2-1

TABLE 1
HEATING VALUES OF BIOMASS

Material	kcal/kg+	Btu/lb+
Latex (Coagulum)	10,950	19,700
Fir Bark	5,280	9,500
Redwood Hogfuel	4,910	8,840
Spruce Hogfuel	4,770	8,590
Cottonseed Hulls	4,780	8,600
Grain	3,960	7,130
Pecan Shells	4,500	8,100
Citrus Rinds	940*	1,700*
Corn Cobs	4,450	8,000
Coffee Grounds	5,560	10,000
Shelled Corn	4,750	8,550
Cotton, Unprocessed	3,630	6,540
Grass	3,930	7,070
Leaves	3,610	6,500
Brush	4,060	7,300
Rice Hulls	4,720	8,500

+ Naturally occuring state of materials (presumed to be partially dried)
* Heating value as fired presumed to be as received.

Table 2
TYPICAL ANALYSES OF BAGASSE

	Percent by Weight					Heating Value Btu per lb		Atmos. Air at Zero Excess Air lb per 10^6 Btu	CO_2 at Zero Excess Air, percent
	Carbon C	Hydrogen H_2	Oxygen O_2	Nitrogen N_2	Ash	Higher	Lower		
Cuba	43.15	6.00	47.95	—	2.90	7,985	7,402	625	21.0
Hawaii	46.20	6.40	45.90	—	1.50	8,160	7,538	687	20.3
Java	46.03	6.56	45.55	0.18	1.68	8,681	8,043	651	20.1
Mexico	47.30	6.08	35.30	—	11.32	9,140	6,548	667	19.4
Peru	49.00	5.89	43.36	—	1.75	8,380	7,807	699	20.5
Puerto Rico	44.21	6.31	47.72	0.41	1.35	8,386	7,773	625	20.5

Table 3
TYPICAL ANALYSIS OF DRY WOOD*

	Percent by Weight						Heating Value Btu per lb		Atmos. Air at Zero Excess Air lb/10^6 Btu	CO_2 at Zero Excess Air Percent
	Carbon C	Hydrogen H_2	Sulfur S	Oxygen O_2	Nitrogen N_2	Ash	High	Low		
SOFTWOODS										
Cedar, white	48.80	6.37	—	44.46	—	0.37	8,400*	7,780	709	20.2
Cypress	54.98	6.54	—	38.08	—	0.40	9,870*	9,234	711	19.5
Fir, Douglas	52.3	6.3	—	40.5	0.1	0.8	9,050	8,438	720	19.9
Hemlock, western	50.4	5.8	0.1	41.4	0.1	2.2	8,620	8,056	706	20.4
Pine, pitch	59.00	7.19	—	32.68	—	1.13	11,320*	10,620	702	18.7
white	52.55	6.08	—	41.25	—	0.12	8,900*	8,308	723	20.2
yellow	52.60	7.02	—	40.07	—	0.31	9,610*	8,927	710	19.3
Redwood	53.5	5.9	—	40.3	0.1	0.2	9,040	8,498	722	20.2
HARDWOODS										
Ash, white	49.73	6.93	—	43.04	—	0.30	8,920*	8,246	709	19.6
Beech	51.64	6.26	—	41.45	—	0.65	8,760*	8,151	729	20.0
Birch, white	49.77	6.49	—	43.45	—	0.29	8,650*	8,019	712	20.0
Elm	50.35	6.57	—	42.34	—	0.74	8,810*	8,171	715	19.8
Hickory	49.67	6.49	—	43.11	—	0.73	8,670*	8,039	711	20.0
Maple	50.64	6.02	—	41.74	0.25	1.35	8,580	7,995	719	20.2
Oak, black	48.78	6.09	—	44.98	—	0.15	8,180*	7,587	714	20.5
red	49.49	6.62	—	43.74	—	0.15	8,690*	8,037	709	19.9
white	50.44	6.59	—	42.73	—	0.24	8,810*	8,169	715	19.8
Poplar	51.64	6.26	—	41.45	—	0.65	8,920*	8,311	716	20.0

* Calculated from reported high heating value of kiln-dried wood assumed to contain 8 percent moisture.

In order to better understand the combustion theory and evaluate the combustion of various biomass fuels with fossil fuels five examples of combustion calculations follow.

These examples of combustion calculations for biomass and fossil fuels were prepared assuming the pressure is at sea level and the air contains 0.13 kg of water per kg of dry air or .013 lbs of water per lb of dry air. The analysis of fuel as fired is shown for each fuel used in the examples. The fossil fuel examples are shown to develop the theoretical air quantities for complete combustion with a biomass fuel. See Sample Biomass Combustion Calculations in Table 4.

The specific gravity of the flue gas can be divided by the density of air at any condition of temperature or pressure and multiplied by the weight of flue gas to obtain the actual gas volumes for the boiler exit and back end equipment conditions.

Volume of flue gas/min = $\frac{S_g \times W_x \; t_1 \times P_1}{d_a \times t_o \times P_o \times 60}$ in which S_g is the specific gravity of the flue gas per hour in kilograms, t_1 is the flue gas temperature in degrees Kelvin, and P_1 is the flue gas pressure in centimeters of water, d_a is the density in cubic meters per kilogram at

TABLE 4

SAMPLE BIOMASS COMBUSTION CALCULATIONS

Rice Husk Annual Production 50,000,000 kg/yr

$$\text{Use Rate} = \frac{50,000,000}{350\ \text{da/yr} \times 24\ \text{hr/da}} = 5952.38\ \text{kg/hr}$$

Ultimate Analysis:

Ash	=	19.13%	Nitrogen	=	0.46%
Moisture	=	5.72%	Sulfur	=	.07%
Carbon	=	39.71%	Oxygen	=	29.90%
Hydrogen	=	5.01%	Total	=	100.00%

HHV = 3542 kcal/kg

30% Excess Air

5952.38 x 5.018 x 1.3 = 38,834.4 kg/hr

Flue Gas Weights

Weight of combustion air	=	38,834.4 kg/hr
Weight of fuel	=	5,952.4 kg/hr
H_2O in air (.013 x 38,834.4)	=	504.8 kg/hr
Weight of flue gas	=	45,291.6 kg/hr

Moisture in Flue Gas

Fuel moisture (.0572 x 5952.38)	=	340.43 kg
Moisture from H_2 (9 x .0501 x 5952.38)	=	2683.93 kg
Moisture in air (.013 x 38,834.4)	=	504.85 kg
Weight of moisture in Flue Gas	=	3529.26 kg

$$\text{Percent moisture} = \frac{3529.26}{45291.6} = 7.8\%$$

Stoichiometric Air

$$SA = 11.53\ C + 34.34\ (H - \frac{O}{8} \quad 4.29\ \ S$$

$$= 4.578 + .4370 + .0030$$

$$= 5.0186\ \text{kg air/kg fuel}$$

Molecular Weight of Dry Flue Gas from PGP Chart

O_2	=	4.9%	N_2	=	100 - 20.7
CO_2	=	14.8%	N_2	=	79.4
A	~	1.0%			
Subtotal		20.7%			

$$MWg = .049(32) + .148(44.01) + .010(39.944) + .794(28.016)$$
$$= 30.73\ \text{kg/kg mol.}$$

Specific Gravity of Flue Gas (Relative to Air)

$$SG = \frac{(100 - 7.79)\ 30.69}{100 \times 28.966} + \frac{7.79 \times 18.016}{100 \times 28.966}$$

$$SG = .977 + .048 = 1.025\ \text{times that of air}$$

273.15°K. t_o is the standard temperature 273.15°k, and P_o is the standard atmospheric pressure at 1033.25 cm of water.

Since most biomass fuel will be accompanied by some auxiliary fuel, sample calculations for obtaining the theoretical air requirements are given in Table 5 for a coal, in Table 6 for an oil, Table 7 for a natural gas and Table 8 for a dry, suspension-fired wood dust.

Table 5

SAMPLE COAL CALCULATIONS FOR THEORETICAL AIR

Ultimate Analysis

wt/wt of fuel as fired	Divisor	Moles of O_2	Multiplier	Moles of N_2
C = .720	12	.0600		
H_2= .044	4	.0110		
O_2= .036	-32	(- .0011)		
N_2= .014	28	-		.0005
S = .016	32	.0005		
H_2O = .080	-	-		
Ash = .090	-	-		
Sum = 1.000	Moles O_2 required =	.0704	3.76	.2647
			Moles of N_2 =	.2652

Moles of dry air = O_2 + N_2 = .0704 + .2652 = .3356

Weight of dry air = .3356 x 28.966 = 9.7210
(as kg of air/kg of fuel or lb of air/lb of fuel)

Weight of wet air = (9.721)+.013 (moisture) = 9.8474

Theoretical air = 9.8474 kgs air/kg fuel or lbs air/lb fuel

Table 6

SAMPLE BUNKER C OIL CALCULATIONS FOR THEORETICAL AIR

Ultimate Analysis wt/wt of fuel as fired			Divisor	Moles of O_2	Multiplier		Moles of N_2
C	=	.879	12	.0733			
H_2	=	.103	4	.0258			
S	=	.012	32	.0004			
O_2	=	.005	-32	(-.0002)			
N_2	=	.001	28	-			-
Sum	=	1.000	Moles O_2 required =	.0993	3.76	=	.3734
					Moles of N_2	=	.3734

Moles of dry air = O_2 + N_2 = .0993 + .3734 = .4727

Weight of dry air = .4727 x 28.966 = 13.6922
as kgs of air/kg of fuel or lbs of air/lb of fuel

Weight of wet air = (13.6922) 1+.013 (moisture) = 13.8702

Theoretical air = 13.8702 kgs air/kg fuel or lbs air/lb fuel

Table 7

SAMPLE NATURAL GAS CALCULATIONS FOR THEORETICAL AIR

(volumetric analyses 1 liter)

Volumetric Analyses	Multipliers for $C+\frac{H}{4}$	Liters of O_2	Multiplier for N	Liters of N_2*
CH_4 = .853	1 + 1	1.706		
C_2H_6 = .126	2 + 1-1/2	.441		
O_2 = .003		(-.003)		
N_2 = .017				.017
CO_2 = .001				.001
Sum = 1.000	liter O_2 =	2.144	3.76	8.061
			liters of N_2 =	8.079*

Liters of dry air = $O_2 + N_2^* = 2.144 + 8.079 = 10.223$

Liters per gram-mole @ 20°C = $22.412 \times \frac{293}{273} = 24.054$

Weight of dry air = $\frac{10.223}{24.054} \times 28.966 = 12.311\text{g}$

grams of air/gram of fuel or lbs of air/lb of fuel

Weight of wet air = (12.311)1+.013 moisture = 12.471

Theoretical air = 12.471 kg air/kg fuel or lbs air/lb fuel

* CO_2 in original gas

Table 8

SAMPLE DRY WOOD DUST CALCULATIONS FOR THEORETICAL AIR

Ultimate Analysis of Dry Wood		Divisor	Moles O_2		Multiplier		Moles N_2
C =	.5010	12	.0418				
H_2 =	.0634	4	.0159				
O_2 =	.4173	-32	(-.0130)				
S =	.0002	32	-				
N_2 =	.0032	-	-				.0032
Ash =	.0159	-	-				-
Sum =	1.0000	Moles O_2 =	.0447	x	3.76	=	.1681
					Moles N_2	=	.1713

Moles of dry air = O_2 + N_2 = .0447 + .1713 = .2160

Weight of dry air = .2160 x 28.966 = 6.2567
(in kgs of air/kg of fuel or lbs of air/lb of fuel)

Weight of wet air = 6.2567 (1+.013) = 6.3380

Theoretical air = 6.338 kgs fuel/kg air or lbs fuel/lb air

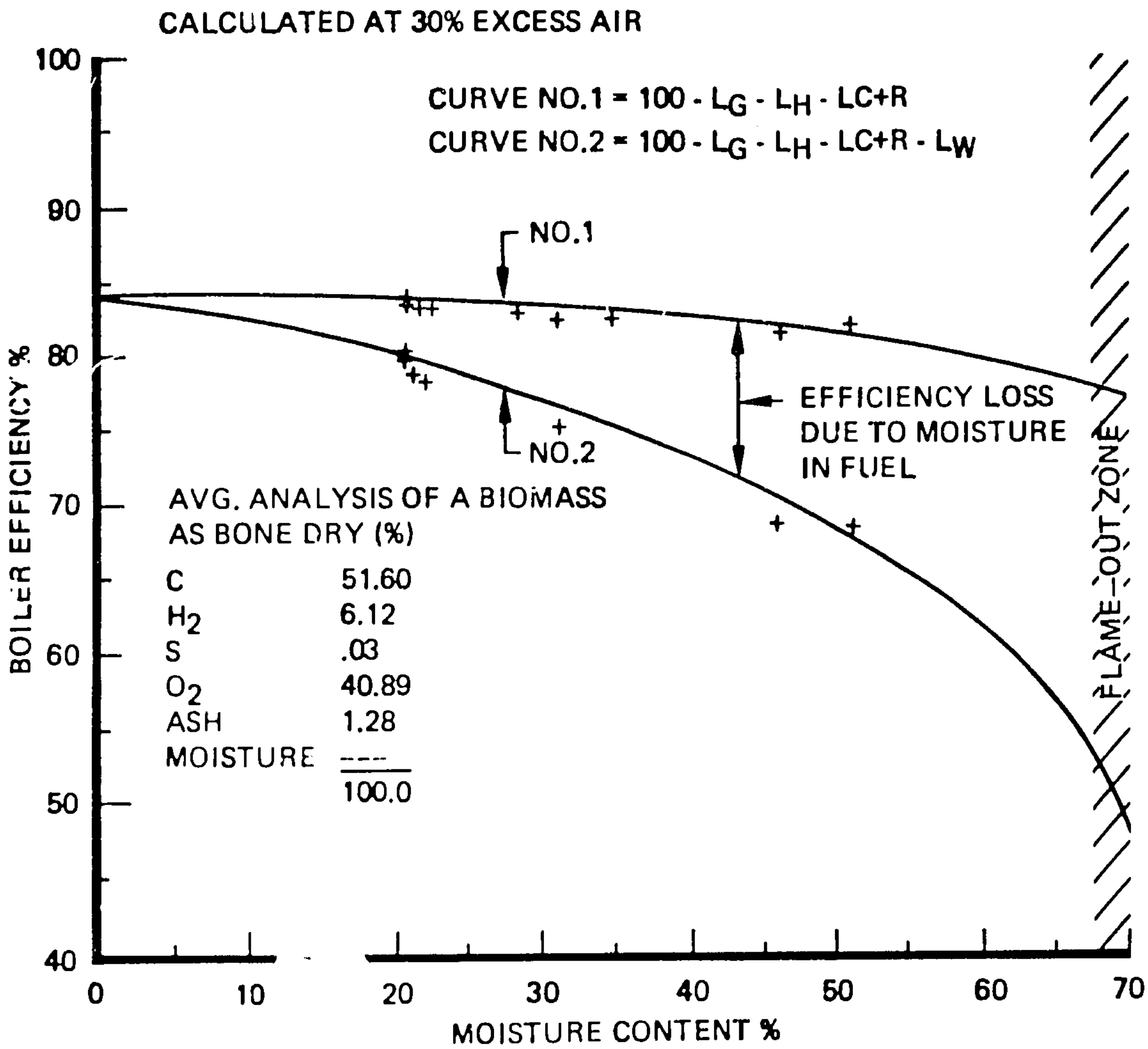
Where more than one fuel is burned simultaneously, the total air requirement is the summation of the theoretical and excess air requirements of each fuel component. Generally, the slower burning of the biomass fuels is "base loaded" and its air requirement is adjusted to sustain its combustion. The other fuels are more easily fed to meet the varying heat requirements of the system so their air requirements are controlled to pace the rate of auxiliary fuel being fired. The designer may select several different fuels that can be fired in this manner.

As previously mentioned, moisture in the fuel will greatly influence net heat output of a boiler. Heat is necessary to evaporate the moisture from the fuel and this heat for evaporation comes from the fuel itself, and therefore, reduces the boilers ability to put heat into the final steam end product. As will be seen later, this factor has a major effect on furnace and boiler design. The evaporated fuel moisture also takes up space in the furnace reducing the residence time of the hot combustion products in the boiler. Both factors reduce boiler operating efficiency.

Losses make up a large portion of the heat balance in combustion calculations. Unburned carbon, CO gas in lieu of CO_2 and heat lost up the stack constitute the majority of these losses. Radiation and external convection losses are normally controlled by design and insulation, and therefore, account for a very small part of the losses in the heat balance. Unburned carbon and combustion of CO gas can be recovered to produce useful heat by special design considerations in the fuel firing equipment. These considerations may impact the furnace design, the fuel feeding equipment and the fuel moisture content and size of the fuel that is fired.

Babcock and Wilcox, a large boiler manufacturer, has stated that the greatest heat loss is the loss up the stack. Since the heat in the fuel is determined from a base of ambient temperature, all the products of combustion must be cooled to this temperature if all the heat is to be utilized. Higher exhaust temperatures then represent a loss, which is the sum of four items: (1) The sensible heat in the dry combustion products, (2) the sensible heat in the moisture that was in the air, (3) the sensible heat in both the water from combustion and the moisture content in the fuel and (4) the latent heat of the moisture content in the fuel. The importance of moisture in combustion efficiency should not be underestimated. See Figure 2-2 for an example that shows the drop in boiler efficiency that occurs when wet wood is burned. Flame out occurs

LOSSES AFFECTING BOILER EFFICIENCY
METHOD USED: ASME PTC 4.1-b



BE =BOILER EFFICIENCY = 100 - (L_G+L_H+L_{C+R}+L_W)

L_G =HEAT LOSS DUE TO DRY GAS $= \frac{W_G \times SP.\ HT \times (t_2 - t_1) \times 100}{HHV}$

W_G =WEIGHT OF STACK GAS/LB. OF FUEL

SP. HT =SPECIFIC HEAT (0.24)

t_1 =TEMPERATURE OF INCOMING AIR 70°F

t_2 =TEMPERATURE OF STACK GAS 400°F

HHV =HEAT VALUE AS RECEIVED IN BTU/LB

L_W =HEAT LOSS DUE TO MOISTURE (%)

L_H =HEAT LOSS DUE TO H_2O FROM COMBUSTION OF H_2 (%)

L_{C+R} =HEAT LOSSES DUE TO COMBUSTIBLE IN REFUSE AND RADIATION (%)

29033-89

Figure 2-2

at about 68% moisture when calculated on a wet (as received) basis.

Table 9 shows the suggested range of excess air required for various types of fuel-burning equipment. Note that there is a wide variation for any given fuel which is dependent on the configuration, air duct capacities, grate openings and many other aspects of the design of the fuel burning equipment. This fact is extremely important when considering a conversion from one fuel to another and what modifications must occur.

Table 9

EXCESS AIR AT FURNACE OUTLET

	Fuel	Excess air in %
Solid fuels	Coal	10-40
	Coke	20-40
	Wood	25-40
	Bagasse	25-45
Liquid fuels	Oil	3-15
Gaseous fuels	Natural gas	5-10
	Refinery gas	8-15
	Blast furnace gas	15-25
	Coke oven gas	5-10

COMBUSTION SYSTEMS APPLICATIONS

The direct combustion of biomass for the production of heat energy can be divided into four basic system groups. The distinct groups, in an approximate order of increasing technology, are as follows:

- o Pile Burning
- o Stoker Fired Grate Burning
- o Suspension Burning
- o Fluidized Bed

These groups can be distinguished essentially by understanding the relative differences in the ways which the fuel is burned. The name of each group reveals something of the intrinsic characteristics of each system. Pile burning does, for example, make use of an actual pile of fuel with which to maintain the combustion process. Bark and slabs of wood can be ground up and fired by a spreader-stoker device over a grate. Grate burning involves the use of a grate through or over which spent ash is separated from the incoming fuel. Suspension burning can eliminate the need for a grate, in that the fine fuel particles are burned in suspension with air, much like an oil or natural gas combustion flame. Fluidized bed technology allows the fuel to burn in a floating and agitated "bed" mixture of fuel and noncombustible mineral.

Each method has its own advantages and disadvantages in comparison to the others, but the actual judgment of what is an advantage or disadvantage is most often a matter of careful consideration of the particular place and situation in which the system is to be used. Advanced systems which were developed for their advantages in efficiency and/or fuel and ash handling capabilities near a highly industrialized center may be completely inappropriate in a less developed location. Nevertheless, in the interest of showing the full range of technology which is currently available, all four combustion methods are included for review.

Pile Burning

The three systems available for pile burning are the Dutch oven, cyclonic and fuel cell types.

Dutch Oven

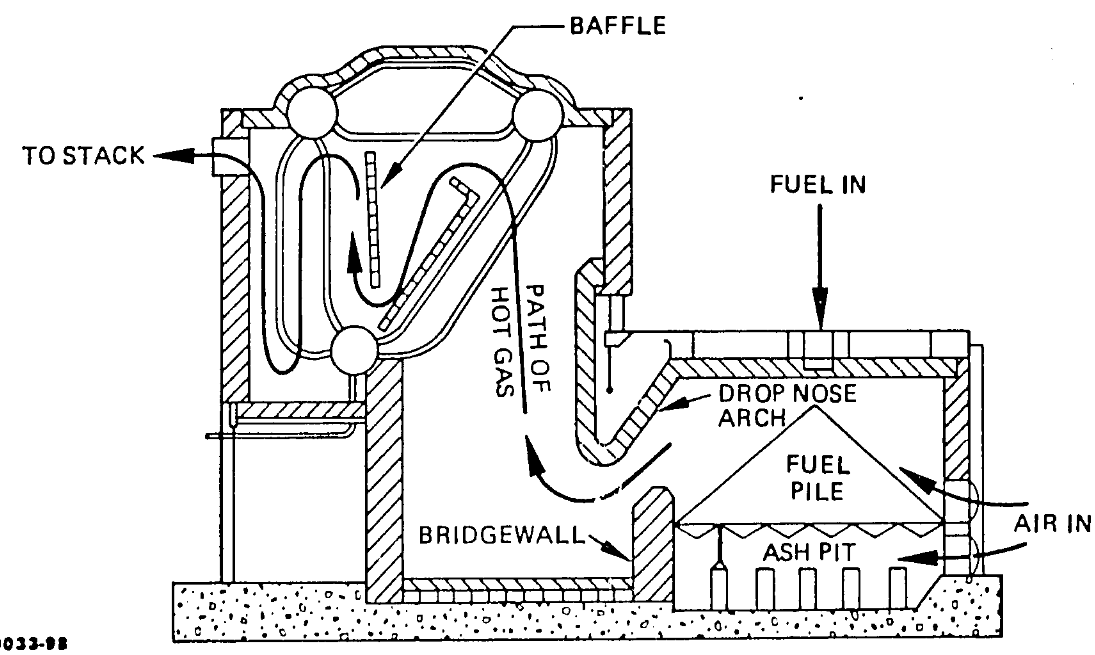
Of all the systems of combustion now available, the Dutch oven is probably the oldest still in use. This pile burning system has seen long use in the forest product and sugar industries, in particular.

The standard Dutch-oven installation is a two-cell furnace built up of heavy refractory walls with a grate in the bottom and tuyeres in the walls through which combustion air is supplied. Fuel is introduced into the furnace through openings in the walls or the roof to form a conical pile on the grate. Drying of the fuel, along with gasification, takes place in the first compartment, and the combustion of the gases produced from the volatile matter occurs in the second compartment. Because pile burning is mostly a matter of surface combustion the use of refractory arches and walls in the first chamber is essential. These refractory surfaces provide the maximum amount of radiant and reflected heat for maintaining evaporation and gasification. They are also important in preventing the fire from being smothered with new fuel dropping on the surface of the pile.

The size and shape of the cells depends on many variables. Type of biomass, moisture content, pretreatment of fuel, number of fuel openings, use of preheated combustion air, etc. all influence the design. For example, since a high moisture content fuel would require more radiation from the arch, overfire air must be more thoroughly mixed with the gas and the velocity of the gas through the furnace must be slower. However, the characteristics of the Dutch oven are such that they can be designed for many types of fuel and, with some compromise in design, variations in a given fuel composition can be accommodated. It is desirable that the maximum size of the fuel be limited, accomplished by passing the fuel through a hog or grinder, and that the moisture content be fairly uniform.

Dutch ovens may be fitted with steam generators ranging from fire-tube boilers generating saturated steam at 1730 kPa (250 psi) to water-tube units producing superheated steam. Because of size restrictions, however, steaming rates have an upper limit. To achieve greater steam production, two or more cells may be installed under a boiler. Figure 2-3 shows a boiler with a dutch-oven furnace.

BOILER WITH A DUTCH-OVEN FURNACE



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In installations that have a fluctuating biomass fuel supply, auxiliary fuel burners may be placed in the second chamber to provide heat during periods of primary fuel shortage. Other accessories may include only a natural draft air supply or may advance to forced-draft and induced-draft fans, water-cooled grates, economizers, air-preheaters and mechanical dust collectors.

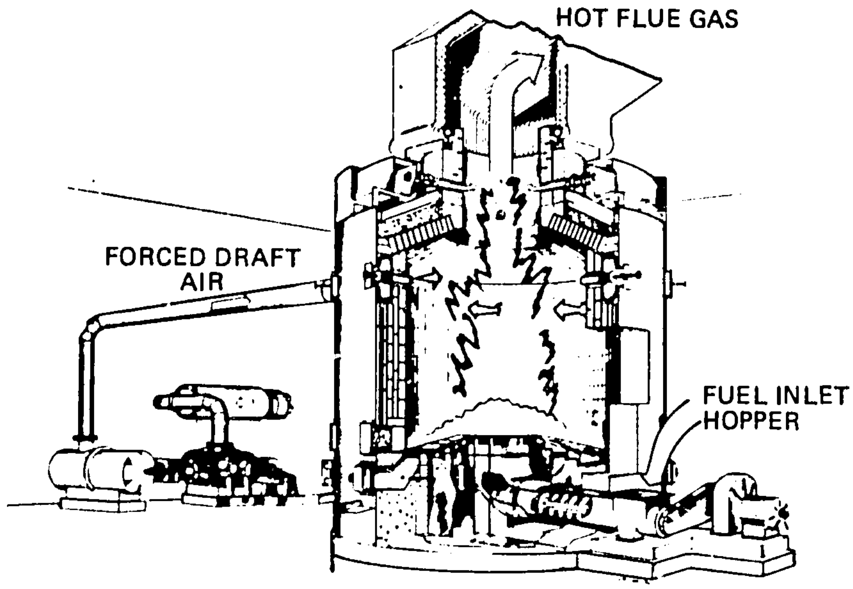
Dutch ovens deliver a steady rate of heat output and can handle 25% to 50% moisture in fuels. On the other hand, they do not handle load changes or fuel wetter than 50% moisture well because of the heat-reservoir effect built into the burning fuel pile and the large refractory area and wet waste fuel mass. However, when there is a dependable supply of relatively moist, coarse fuel and a steady small-to-medium heat requirement, a Dutch oven type of installation should be considered.

Cyclonic

A second type of a pile burning system is the cyclone furnace. A type of cyclone furnace is built by Axon and used primarily in Scandinavia. The furnace is in the form of a vertical cylinder, with the fuel introduced at the bottom by an underfeed stoker. The hot products of combustion exit at the top into a water-cooled duct leading to the boiler. The walls and the roof are built up from refractory brickwork. The wood fuel is fed by a screw into a retort in the center of the furnace bottom. The fuel forms a pile spreading out from the center of the fixed, circular grate bars to the outer edge. Ash accumulates at the periphery. Figure 2-4 shows the cyclone furnace principal.

Figure 2-4

TYPICAL VERTICAL CYCLONE FURNACE



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Preheated, primary air is fed through the grate. Relatively high-pressure, cold, secondary air from a blower is blown in tangentially at the top of the furnace to produce a cyclone effect. In the throat, tertiary air is introduced for final combustion of the gases leaving the furnace.

Some of the advantages of the cyclone furnace are high combustion efficiency, low dust emission, good-burn-out and the ability to burn wet fuel. Some off-setting disadvantages are low capacities per furnace, ash disposal not lending itself to automation, maintenance costs of refractory, and high power consumption. However, a multiple furnace installation under the boiler will aid in achieving higher steaming rates. Considering the high combustion efficiency and ease of operation, the cyclone furnace is definitely a viable system for relatively small heat requirements.

Fuel Cell

The fuel cell or single chamber combustor consists of a primary combustion furnace of many shapes in plan view, usually circular, in which fuel is stoker fed or dropped onto a pile supported by a fixed grate. Air is introduced under the grate and initiates the combustion process with the help of heat radiated from the refractory covered walls of the furnace. Combustion is completed in the furnace (combustion chamber) of a boiler located above the fuel cells. The system is suited to boilers up to about 27,000 kg/hr (60,000 pph) and may be adapted to fire tube as well as water tube steam generators. Figure 2-5 shows a Single Chamber Silo Burner.

ENERTHERM INC.
SINGLE CHAMBER SILO BURNER

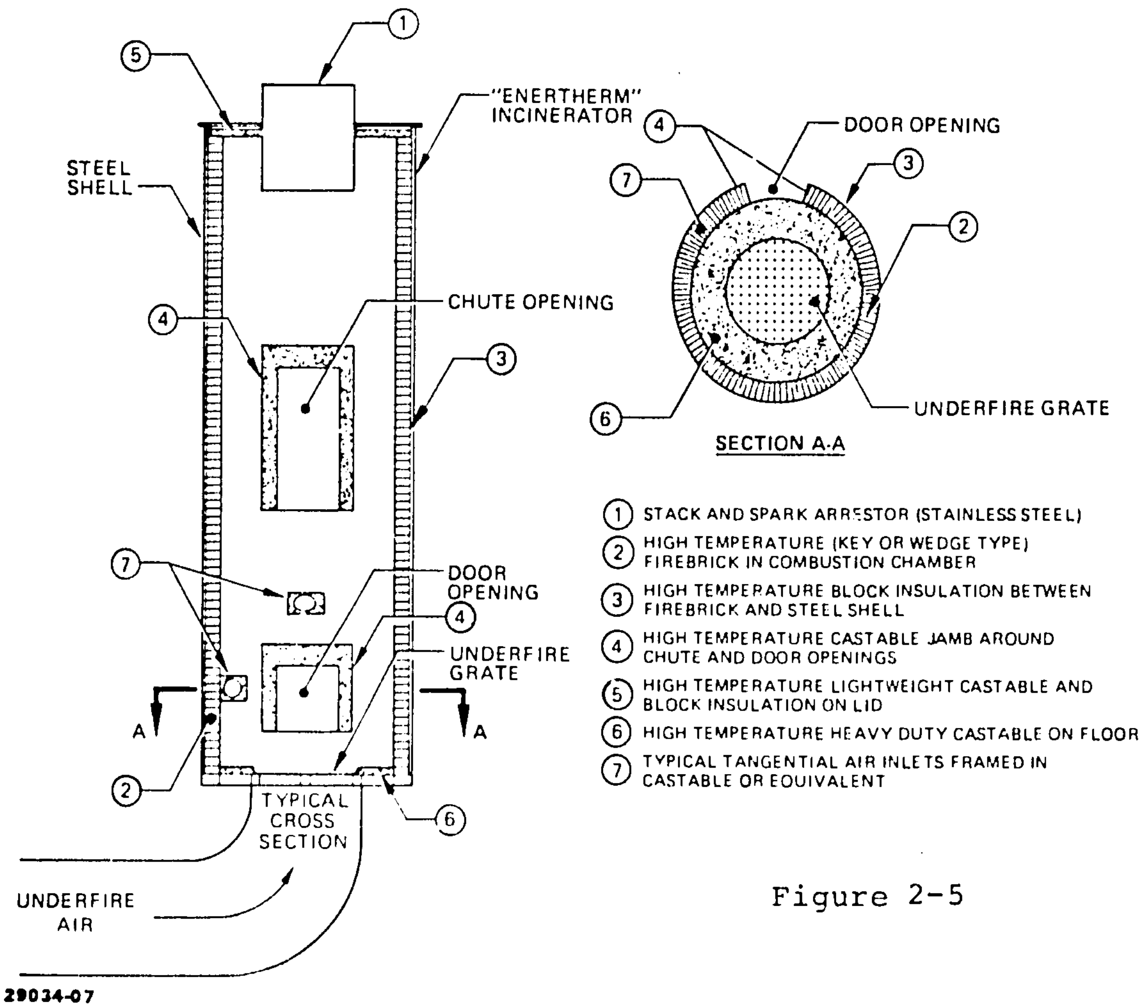


Figure 2-5

Stoker Fired Grate Burning

Stokers

Stokers are devices that place and distribute fuel on a grate where burning, for the most part, occurs (on the grate of the furnace.) One of the most common ways of firing 75 mm-(3-inch) minus woody fuel is a spreader-stoker. Grate burning boilers using this system are more or less confined to rather small grate areas, generally generating about 2,000,000 to 3,000,000 $\frac{\text{k cal}}{\text{m}^2\text{h}}$ (750,000 to 1,100,000 $\frac{\text{Btu}}{\text{sf/hr}}$) with a residence time for combustion of about 2-1/2 to 4 seconds. This information is introduced here to give a reference rate of heat release for the grates and furnaces discussed in this section.

Grate firing of biomass fuel can be divided into two broad categories: stationary grates and moving grates.

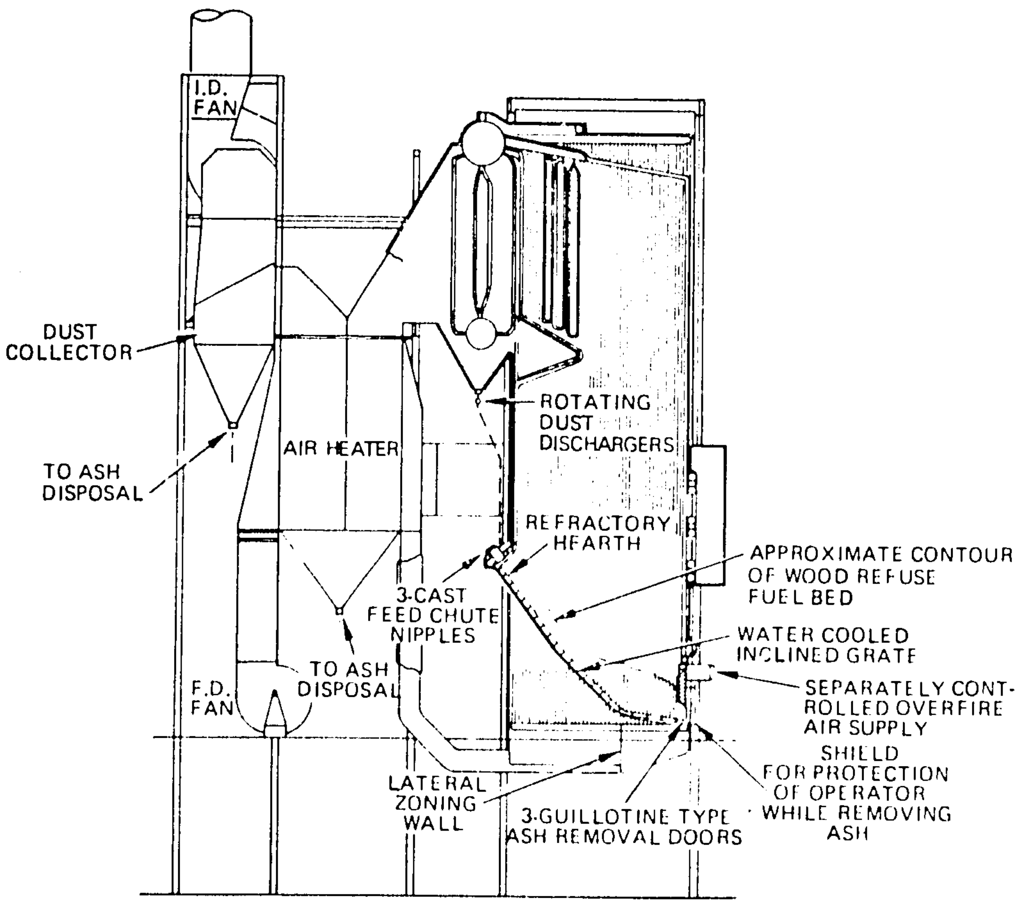
Stationary Grates

Flat, stationary grate furnaces were among the earliest in use for waste wood firing. While the earlier models served a useful function in the past and many are still in use in the U.S., the disadvantages are such that many have been replaced with advanced-design furnaces in which improved fuel feeding and burning equipment are used. This type of furnace has an inherent size limitation, but it is quite satisfactory for many, smaller applications. Figures 2-6 and 2-7 show two types of a stationary grate.

The fixed, sloping-grate, steam generators are manufactured in the U. S. and Europe for wood fuel firing. One major U. S. supplier incorporates a steeply sloping grate, the low end being at the boiler front wall, the angle of slope being continuous throughout the length of the grate. Fuel is introduced with mechanical or pneumatic distributors and is thrown to the high end toward the rear wall, with some fuel being burned in suspension. The grate proper consists of spaced, water-filled tubes with cast alloy blocks bolted to the top, fitted closely together, forming a continuous flat surface. About 75% of the combustion air is admitted to the furnace through pin holes in the grate blocks. The remaining air is introduced through wall ports as overfire air. Figure 2-6 is an illustration of a boiler with a fixed sloping grate.

Figure 2-6

WOOD-FIRED INCLINED GRATE



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SMALL SPREADER STOKER FURNACE

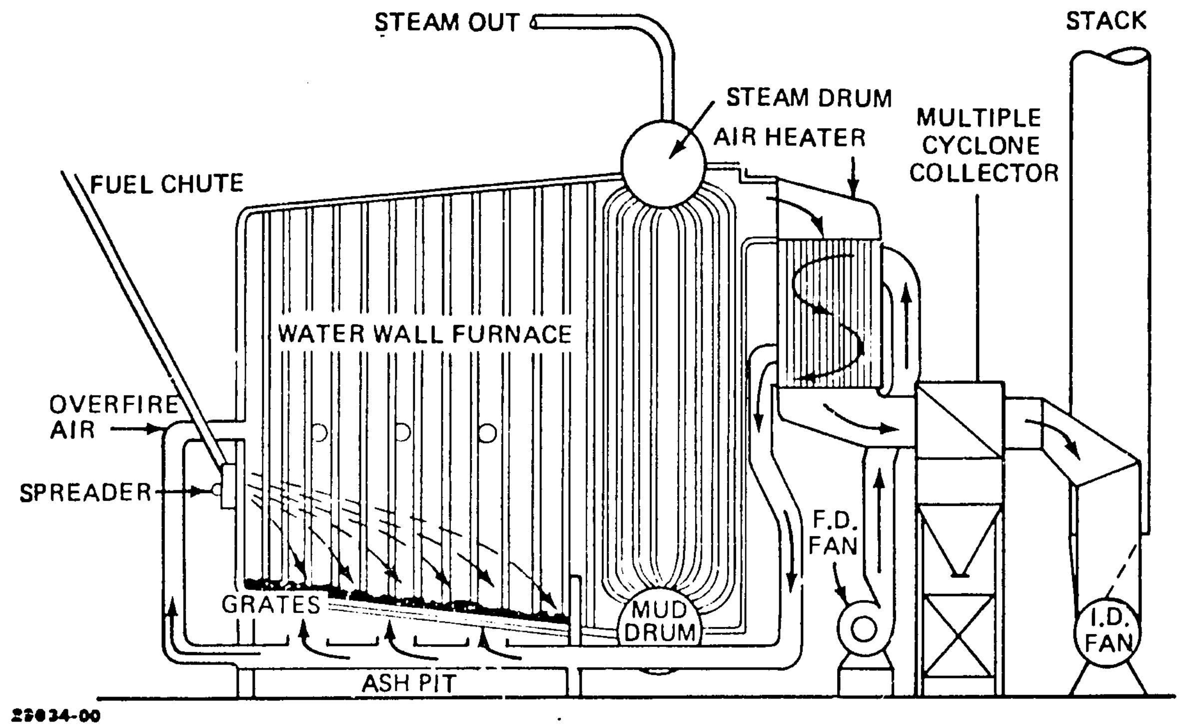


Figure 2-7

During operation, accumulated ash is advanced continuously by pulsating steam jets from nozzles located within selected grate segments. The motive energy provided by these jets propels the ash down the sloping grate surface into the ash hopper.

The European, sloping grate design differs from U.S. designs, in that the angle of the slope is not constant over the length of the grate but approaches the horizontal in stages. The grate is a membrane wall with air holes through integral fins. The air holes are protected by small deflector plates welded to the fins. The deflector plate directs the air in the direction of the down-slope of the grate to help advance the ash and fuel bed as well as support combustion.

Also, the plates help prevent fuel fines and ash from plugging the holes or dropping through the grate into the air plenum below. With this system, the fuel is dropped directly onto the grate at the high end. The fuel and ash slide down the grate as combustion progresses and falls off the lower end into the ash hopper.

Both the European and U. S. types of grates have the capability of burning high moisture content fuel at rates that generate steam in excess of 90,700 kg/hr(200,000 pph). Also, both types require periodic manual raking of the grates, as the jets and the slope are not sufficient to move all the ash to the hopper.

Moving Grates

In contrast to the stationary grate systems there are many types of moving or movable grates. The dumping grate is, for example, an improvement over the older, hand-raked, fixed grates. It is a moving grate made up of grate bars, mechanically linked so they can be rotated, louver-like, approximately 90° to dump ash to a pit below. Underfire air is admitted through holes in the grate bars. These grates are limited to rather small units.

Vibrating grates were first practically used in Europe to burn low-grade lignite and brown coals. They were introduced into the U. S. in the early 1950's and have found acceptance in burning both coal and wood fuels. The grates are usually on a slope and are supported by vertical plates free to move back and forth in a rectilinear direction. The grate structure is made up of air- or water-cooled grate bars fixed to a movable frame. Air distribution is provided from an under-grate plenum divided into compartments formed by the supporting, flexing, support plates. Air flow through the various zones is regulated by dampers.

Fuel is fed at one end of the grate and dries and burns as it moves down the grate with the motion caused by the intermittent, vibratory action of the grate units. The ability of the vibrating-grate stoker to burn a wide range of fuels is mainly attributable to the gently compacting action produced by the vibrations. Heat release rates of approximately 2,300,000 $\frac{kcal}{m^2h}$ $\left(850{,}000\ \frac{Btu}{ft^2hr}\right)$ can be expected when burning hogged wood fuel on this type of grate.

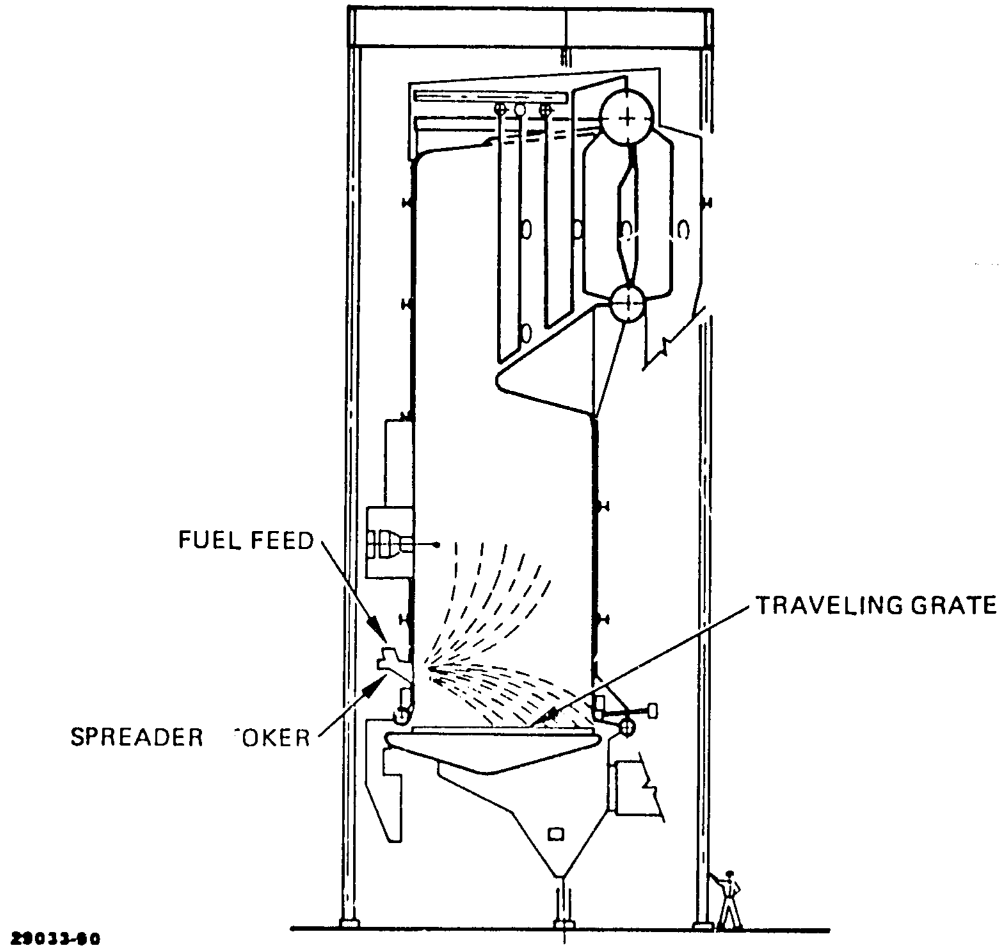
Reciprocating grates are another example of the fuel being moved down a sloping surface by grate action. The grate elements consist of heavy, closely-spaced, alternately fixed and moving, alloy segments. The moving segments are attached to a frame mounted on roller bearings, which is activated by a hydraulic system. The moving bars work intermittently at very low velocity and move the fuel down the grate, the slope of which is about 15°. The ash is also moved in this manner to the lower end, where it drops into the ash hopper.

Frequency and stroke length can be adjusted to allow the depth of the fuel layer to be optimized to give complete combustion and minimize the quantity of unburned char. Underfire air is admitted to the fuel bed through the spaces between adjacent, moving and stationary grate bars and through holes in the bars.

A traveling grate is fundamentally a grate in which the grate surface moves continuously in one direction to convey the fuel bed through the furnace, receiving fuel near one end and discharging ash and clinkers at the other.

Figure 2-8

BOILER WITH TRAVELING GRATE
AND SPREADER STOKER



An example of a traveling grate with a spreader stoker is shown in Figure 2-8. The hogged fuel is normally fed to the furnace by a type of spreader stoker and the fuel is partly burned in suspension on its way down to the grate.

Needless to say, there are various problems on grates and with stokers when burning a low calorific, high voluminous fuel in a boiler, basically designed for a better fuel.

The following difficulties are often reported.

- High particulate emission levels
- High content of unburnt in fly ash
- Uneven distribution on grate and patchy combustion
- High content of unburnt in ashes from the grate
- Difficulties to burn wet wood fuel without support fuel

Grate drives may take several forms. One is a steam turbine or constant speed motor with a variable, reduced-speed transmission permitting a wide variation in grate speed. A second method is a hydraulic-mechanical action which transfers the reciprocating action of a hydraulic-power piston to rotary movement of the grate surface.

Proper grate tension is of importance to maintain alignment of the grate and to prevent jamming. One method to achieve this is by having the idler, or rear, shaft bearings movable by use of a "take-up" mechanism. Another method used to maintain grate tension is to have the lower or return side of the grate hang free so that the weight of an adjustable catenary maintains the proper grate tension.

Feeders and Distributors

The traveling-grate used in conjunction with spreader stokers is probably the most widely used combustion system in U. S. industry today. Almost any type of solid fuel can be burned successfully on various designs of this equipment. Spreader stokers use the combined principles of suspension and stoker firing. Feeding and distributing mechanisms continually project the fuel into the furnace above the ignited fuel bed. The fine fuel particles are burned in suspension, while the larger pieces fall to the grate and are consumed as the grate carries the fuel bed through the furnace.

An even distribution of fuel on the grate is of paramount importance in this type of combustion. A fuel feeder regulates the rate of fuel flow, and a fuel distributor regulates the disposal of the fuel on the grate. Several types of feeders are available. One is a conveyor type which has a drag chain or conveyor belt in the bottom of a chute or hopper, the speed of which is controlled to regulate the rate of fuel flow. With some equipment, weighing devices are available so that the weight of the fuel can be totaled as it is fed. Another device is a twin-screw feeder which has two screws in the bottom of the fuel bin, the speed of which is controlled to vary the fuel feed. A third is a star- or rotary-vane feeder, which is a revolving drum with pockets to feed the fuel out of a bin at varying rates. The rotary feeder, however, is limited to fairly uniform, small, dry, free-flowing materials.

In some instances, it may be advantageous to use one feeder for two or more fuel distributors. In this case a fuel-distributor, swinging-spout assembly may be used. The fuel enters the top of the assembly and is directed by a motor-operated, swinging spout in equal amounts to multiple outlets at the bottom, where the fuel falls by gravity to the distributors below.

There are two basic types of fuel distributors. One type of distributor uses air to move the fuel. After the fuel falls into a chamber from the feeders the fuel is picked up by a stream of high-pressure air sweeping the floor of the chamber and is thrust into the furnace. In some cases the high-pressure air supply to the individual distributors has a rotating damper which produces a pulsating effect on the air stream and helps distribute the fuel more evenly over the bed.

Figure 2-9

TYPICAL PNEUMATIC SPREADER STOKER

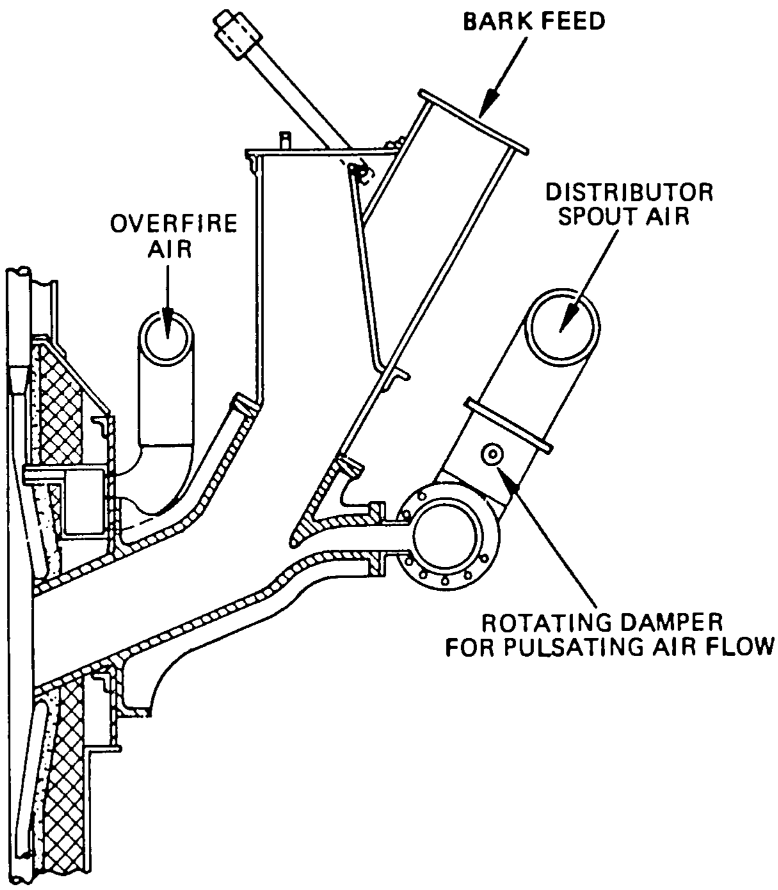


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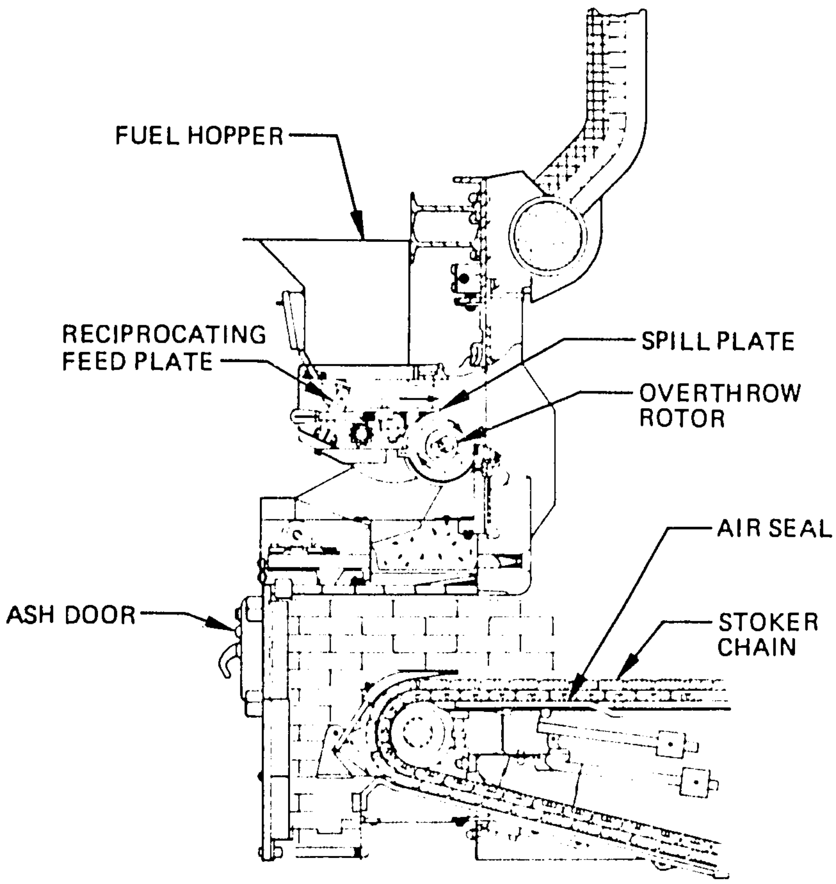
Figure 2-9 shows a pneumatic spreader stoker configuration located at the front wall of the furnace. The second distributing device is a mechanical distributor which has a high-speed, revolving rotor with blades which propel the fuel into the furnace. Usually a variable speed drive is provided for each mechanical distributor to regulate the distribution within the furnace. In addition to the mechanical device, one manufacturer provides a series of closely-spaced, high-pressure air nozzles directly under the distributor spouts to assist in better dispersal of the fuel over the bed of the furnace.

Figure 2-10 shows a configuration for a mechanical distributor to feed fuel into the furnace above a traveling grate.

Figure 2-10

TYPICAL MECHANICAL SPREADER STOKER
OVER A TRAVELING GRATE



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In addition to providing a surface on which the fuel can burn, the traveling grate acts as a conveyor for ashes and provides a platform for drying the fuel; it also provides the openings for passage of the underfire air to the fuel. In some instances, by means of the transversal structural steel shapes that support the grate and the attached air seals, the grate body is divided into air compartments. The air flows into the compartments, and thence throug the grate, and can be regulated by dampers so that the air passing through any section of the grate will correspond to the amount of fuel deposited on that section.

Over-Fire Air

There are many methods used to introduce over-fire air into furnaces. Large nozzles with low-pressure air, nozzles in front, side or rear walls, and tangentally aimed nozzles have all been utilized at some time. The major purpose of over-fire air and its turbulence is to mix the fuel with oxygen in the area of highest temperature. This is especially needed for carbon particles, since they burn slowly and require a high temperature.

In the past, over-fire air quantities were on the order of 15% of total combustion air, currently over-fire air quantities approaching 30% of total air are not uncommon. This air serves the fuel distributors, over-fire turbulence system and cinder reinjection system (if used). Increased quantities of over-fire air should aid in reducing particulate carryover from the furnace. However, a careful balance between over-fire air and under-grate air must be maintained, for an important function of under-grate air is also to cool the grate. Several thermocouples attached to the grate structure can aid in monitoring grate temperature to avoid grate overheating.

For many years, units designed to burn wood fuels have used preheated air under the grates. Modern units with full-steam-load capabilities from wood fuel, now use heated over-fire air for a more efficient combustion, especially for fuels with a high moisture content.

Suspension Burning

Suspension burning of various, finely ground, organic fibers has been successfully accomplished in many installations. Suspension firing requires special furnace features and fuel preparation. Fuels for this type of combustion have upper limits of 14 percent moisture and 0.635 cm (1/4 inch) size.

To obtain the small size particles the fines can be separated from coarser fuel; coarser material can be reduced in size mechanically, or fines can be collected as a manufacturing by-product, sander dust for example. The small particles are conveyed to the burners by an air stream that serves as primary combustion air.

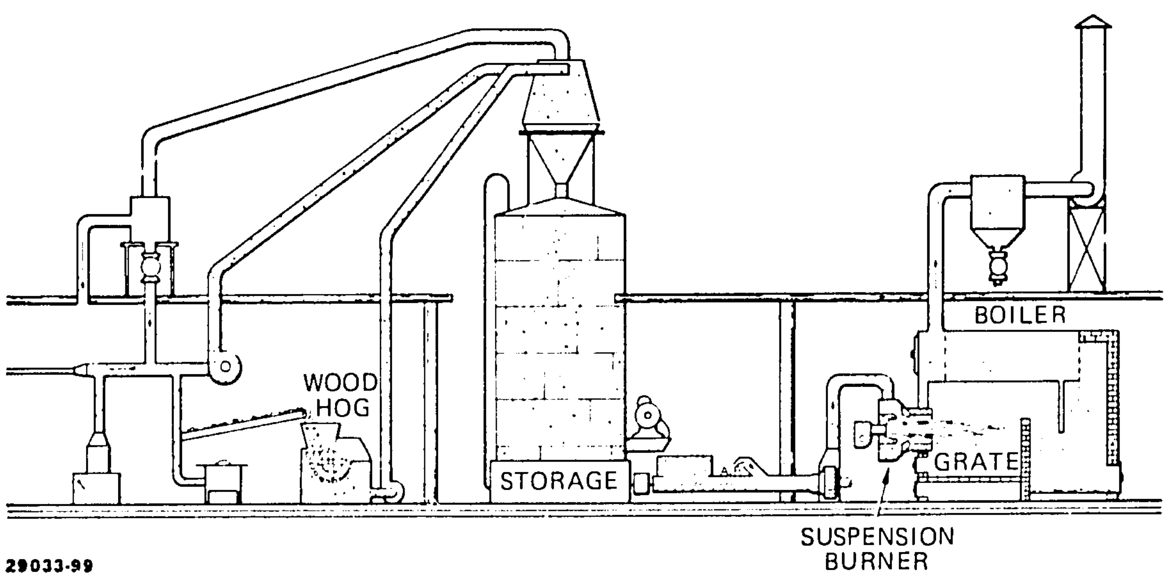
A suspension firing system must provide temperature and turbulence (for air/fuel mixing) for combustion. The correct ignition temperature must be maintained for stable burning. Some burners utilize a gas or oil auxiliary flame to serve as a continuous pilot. In other applications this is not required. For example, a sander-dust burner firing into a Dutch oven often would have sufficient heat radiating from refractory lining of the furnace to aid in maintaining combustion. If the same material were to be fired into a water-wall boiler, it would generally be necessary to have an oil- or gas-sustaining flame, or the burner could have a deep, refractory-lined throat to maintain the necessary high temperature.

Suspension firing of fine biomass materials, such as wood dust, rice husks, nut or seed residue, etc., is similar in some respects to firing oil or gas fuels. They lend themselves to automatic controls and follow load swings rapidly. With proper design, particulate emissions are held down and do not require extensive pollution control at the back of the boiler.

Suspension burning has been used for auxiliary and supplementary heat in grate fired furnaces, the grate being base-loaded and the load swings taken by suspension burners. In addition to generating hot water and steam, these burners are used to heat air for rotary dryers, plywood veneer dryers, lumber kilns, etc. A typical suspension burning system is shown Figure 2-11.

Figure 2-11

TYPICAL SUSPENSION BURNING SYSTEM



Fluidized Bed

Fluidized bed technology has been utilized for several decades for various processes. However, only recently has the process come to the foreground as a serious energy system with the capability of providing a usable energy form, such as hot gas or steam. The major thrust of research and development in fluidized bed combustion has been to establish the capability of burning high-sulfur coal, using limestone or dolomite for the bed material to give a reduced sulfur dioxide (SO_2) emission in the flue gases.

Basically, the process involves blowing air through a distribution plate that will distribute the air evenly across a combustion area. On top of the plate is a bed of fuel and crushed mineral material. The fluidization action takes place when the gas velocity is sufficient to hold the bed particles in mass suspension. The bed mixture serves as a "grate" by supporting (or "floating") the fuel, and the air and combustion gases through the bed provide turbulence with a violent scrubbing action of the particles. The bed also acts as a refractory in radiating heat to the burning fuel. See Figure 2-10, Fluid Bed Combustor.

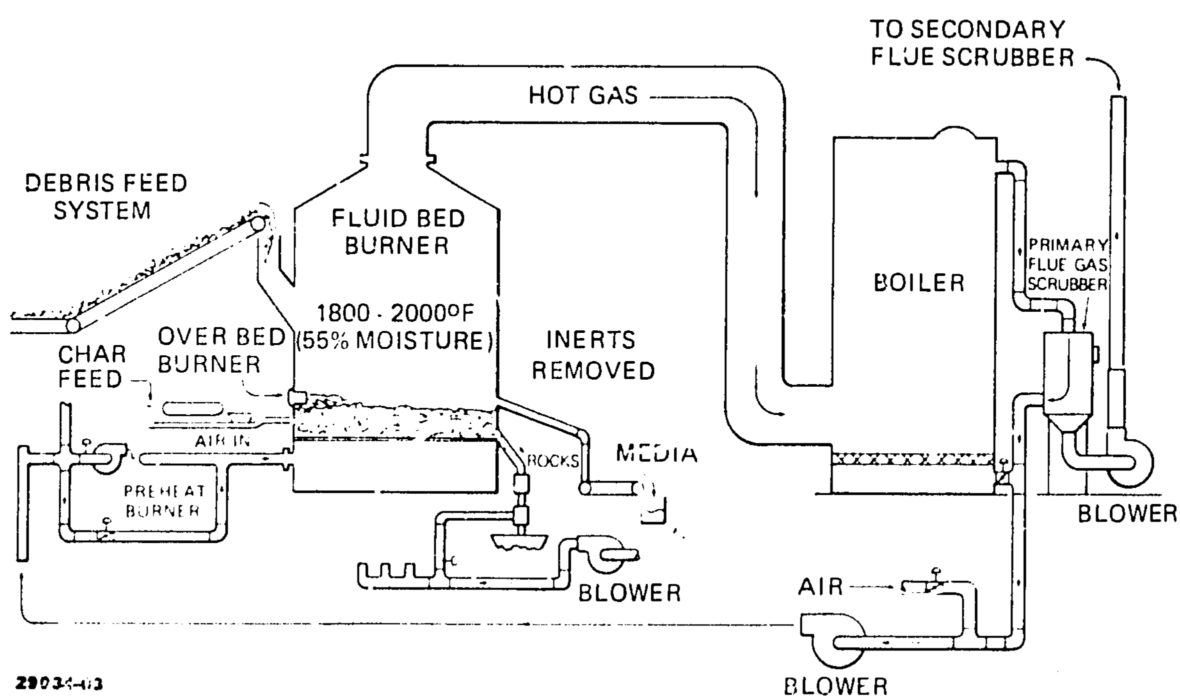
The air supply system is a key element in the fluidized bed combustor. The fan must have sufficient discharge pressure to overcome the head losses through the distributor, bed, combustor intervals, etc. In some cases this pressure drop would be as high as 152 cm of water (60 in. w.g.), in contrast to the 25 or 30 cm water (10 or 12 in. w.g.) pressure required by the air supply of a spreader stoker, and the air blower size and power requirement increase proportionately. The distribution of air must be uniform to prevent short-circuiting through a portion of the bed.

The type of air-feed, fluidization system desired needs to be considered. One system uses only a vertical air distribution, whereas a second creates a definite lateral or circulating air-feed pattern which provides a more even fuel distribution throughout the bed. In addition, the bed media must always have properties that are compatible with each particular application.

A fluidized bed combustion system has an advantage environmentally in that the bed combustion temperature can generally be held at or below 870°C (1600°F), which contributes to the reduction of nitrogen oxides in the flue gas (see ENVIRONMENTAL CONSIDERATIONS). However, as most available U. S. systems were designed to burn

Figure 2-12

FLUID BED COMBUSTOR



coal and to reduce the sulfur dioxide emissions from burning coal, the applications for other types of fuel are presently not fully developed nor explored. The current higher cost for fluidized bed combustors, as compared to other systems, makes it advisable to wait for proof of real economic benefits from fluidized bed combustion of biomass before seriously considering it as an option.

Instrumentation and Control

The control of a wood-fired boiler and turbine-generator is very similar to the control of like units fired by fossil fuels; the only problems are those associated with the variations in fuels. This does provoke design considerations for control of the rate of fuel feed of wood, as compared to coal. But this type of control is essentially the responsibility of the boiler manufacturer. If a proposed fuel and its average characteristics are submitted to the vendor, it is reasonable to expect that the appropriate boiler design will be supplied. However, major variations of fuel type in a boiler could lead to problems, both in combustion efficiency and in heat release control. If the capability of using substantial quantities of alternate fuels is contemplated, this should be discussed with the vendor prior to purchase.

If soft wood-residue fuels, which are reasonably similar in dry basis heating values in the Pacific Northwest, are intended for use in the boiler, there are still many variations in fuel quality on an as-received basis that can affect the combustion characteristics; included among these is moisture content, variation in size, degree of rot and bark-to-wood ratio. As it is rarely possible to eliminate these variations in the quality of the wood fuel, and control over the other functions of combustion is required to compensate for fuel quality variations.

The combustion air supply control function first controlled is the air supply. This in turn is coupled with the air/fuel ratio and determines the rate of fuel input and the rate of fuel advance. The air supply control can be subdivided into controls for other functions, such as undergrate, overfire and reinjection air. When these controls are in proper balance and the air fuel ratio set, then the boiler can compensate for a fairly wide range of fuel conditions and hold the heat release reasonably constant for a uniform steam load. These same controls are also used to adjust the heat release to correspond to changes in steam load, although not instantaneously.

Air combustion controls are generally automatic and operate in response to changes in steam pressure, but they have the capability for manual biasing and override. The control of the fuel feed rate is linked indirectly to the steam pressure by way of the air supply. An excess oxygen sensor in the stack is used to detect and signal the amount of excess air to a recorder in the control room. This may be used to adjust the air fuel ratio.

Other Controls

There are additional controls to stabilize and regulate the steam output of the power plant. A drum level control is used to maintain a constant, drum-water level when increasing or decreasing steam demands. The drum level is stabilized by regulating boiler feedwater flow.

The control of superheat temperature is adapted to the boiler manufacturer's particular design, usually accomplished by a throttling adjustment on the cooling water supply line to the attemperator.

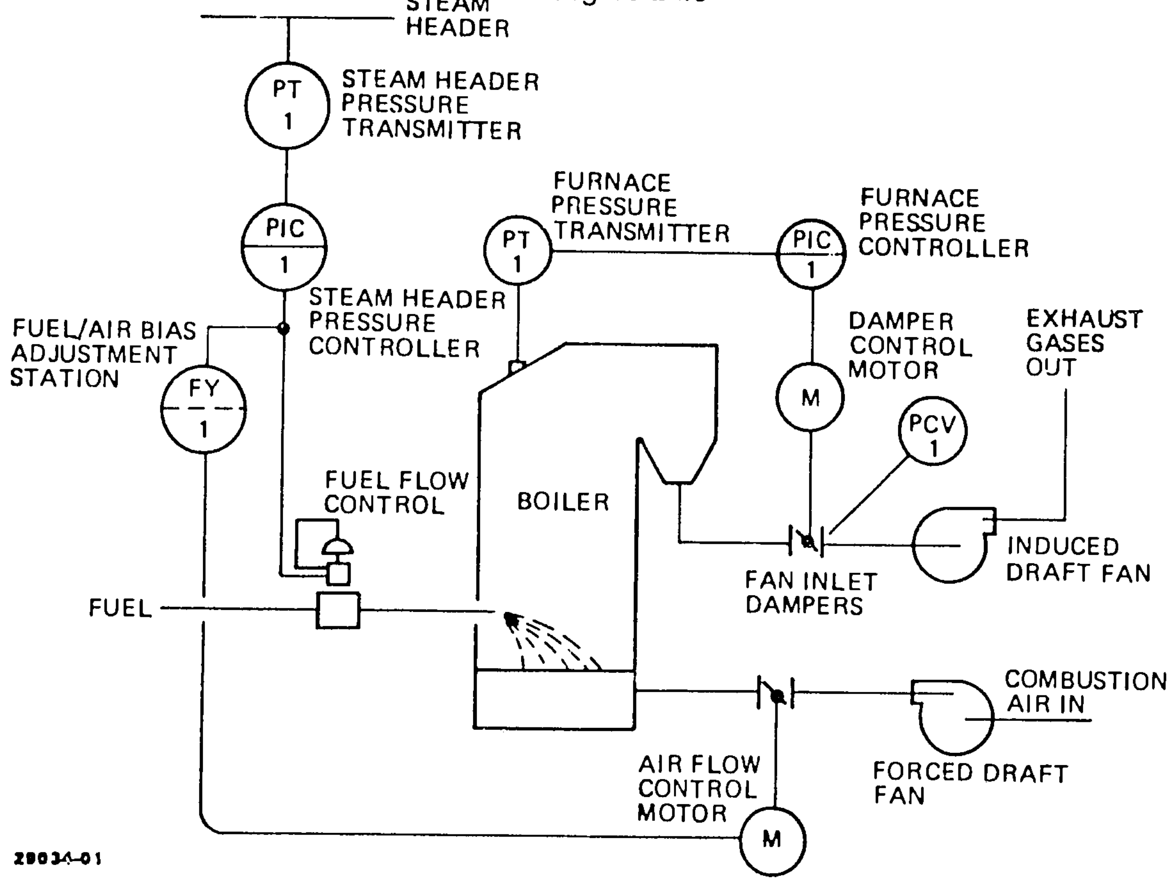
The turbine is controlled from a turbine console panel and may function in either the automatic or manual mode. This control allows for either run-up or run-down of the turbine-generator.

The stack particulate emissions are analyzed continuously to provide data on flue gas opacity. Either a reduction or scattering of a beam of light passed across the discharge and stack monitors and provides the means of sensing and recording continuous opacity readings. As previously described, the oxygen in the flue gas is monitored and the air/fuel ratio is controlled to maintain the highest efficiency of combustion; this is generally synonymous with reduced hydrocarbon, carbon monoxide and particulate emissions from the stack.

Control System Design. With the exception of a few major loops which are brought back to a main control panel, all the systems are based on local pneumatic or electronic control. Pneumatic control requires a non-lubricated or oil-free in-plant, air compressor. A typical

TYPICAL INSTRUMENT CONTROL FOR A BIOMASS FUEL BOILER

Figure 2-13



loop in the control system consists of a locally mounted controller and a control valve. Local instrumentation systems are usually grouped together on racks to facilitate maintenance and adjustment. Typical basic elements of a biomass fuel combustion system for a boiler is shown in Figure 2-13.

The control room generally contains a console control panel. Control stations, televised monitors, indicating meters and recording instruments may be grouped to promote ease of operation and viewing.

FRONT END SYSTEMS

"Front end systems" is the general category of equipment which involves fuel preparation, transfer, and handling. It is the "front end" in the sense that it prepares the fuel for entry into the combustion system, as opposed to "back end" systems (e.g., combustion air preheaters, pollution control, ash handling, etc.) which deal with the by-products of combustion. The front end equipment is a very necessary and important part of a biomass combustion installation, because the raw biomass which is brought to the site must almost always be prepared (i.e., size reduction) and/or transferred from one point to another (e.g., fuel pile to furnace).

Only in rare circumstances could the whole process be considered and designed solely in terms of manual labor; it is not a question of feasibility, but unless the unskilled labor pool is large and the wage scale is very low a totally manual fuel handling process will generally not be economically attractive. Given a large, cheap, labor force and a little ingenuity, however, a primitive system for manually handling the fuel prior to combustion could be worked out. Wheelbarrows and inclined ramps or pulley-hung baskets could be used to elevate the fuel to the combustion feed hopper; some biomass fuels might even be sized adequately by use of hand tools (e.g., machetes, chopping cleavers, etc.) or the combustion system could be set up to directly receive hand-loaded slab wood (pre-cut mill residue for slab-burning).

A combination of both manual labor and machine-powered equipment could also be used in any of various arrangements, best determined by the local engineer or manager. But if any machine hardware is desired, the engineer should be fully aware of the many types which exist, their capabilities, and the logical flow patterns and interconnections. Failure to choose the proper equipment for the job, or the series connection of two inharmonious units, could result in a non-functioning system and a waste of money.

It is possible to design a total fuel processing and handling system that is fully electrical/mechanical. Once the mechanical flow system is understood in terms of its equipment components a designer may choose (with caution) to delete a portion of the powered system and to insert a manual labor operation in order to reduce the capital expenditure. The full, mechanical system, however, almost always incorporates a number of devices that can be classed into one of the two following categories:

- size reduction
- conveying

A third category, fuel drying, may also be included as an option, but there should be an economic justification (a trade-off) for the additional capital expense.

Size Reduction

The amount of fuel size reduction needed is solely a function of the specific combustion system used and of the rate of heat release desired. A slab- or pile-burning system needs the least amount of fuel size reduction; a traveling grate or suspension-burning system needs much more. In terms of the heat release rate, a large-sized fuel will burn more slowly; a fine fuel will burn faster.

It is obvious, of course, that the size of the raw biomass arriving at the site is also a factor in determining the number of size reduction steps required. For example, if the fuel arrives as whole logs larger than 20 cm (8 in.) in diameter, a mechanical splitter and/or cross-cut saws are needed to reduce the size prior to any other steps, even if slab burning is the ultimate use. On the other hand, if the fuel arrives in a crushed or ground condition, very little or no additional work may have to be done in the way of further reduction.

However, assuming that the fuel is delivered as large, whole logs, splitting and cross-cutting will be needed. Mechanical splitters are available in a number of sizes and usually incorporate a sharp wedge applied to one end of the log as it lies horizontally on a cradle. A hydraulic ram at the other end forces the log into the wedge, and the log splits in half lengthwise. Re-splitting into quarters or smaller fractions can be accomplished by the same process.

If the logs are delivered in lengths above 2.4 m (8 ft.), they will generally need to be cut to that length (or less) prior to splitting or any other operation. The logs can be cut to length by any of several cross-cut saw equipment. Large radial saws, either overhead or table-mounted, are commonly used, either singly or in multiple-saw gangs (if the logs are quite long). With overhead radial saws, the saw moves on track at right angles to the log; if the saw is table-mounted, the log has to be moved relative to the saw.

An alternate cross-cutting device is the bar chain saw. One end of the bar is pin-coupled to a fixed point at the ground or transfer deck level, and the bar is free to pivot about that point. When the log is in place the chain drive is turned on, the bar is lowered, and a chain-saw cross-cut takes place. This stationary placement of the chain saw allows a much safer cutting operation than the hand-held machine. But, if a more simplistic, less capital-intensive system is preferred, the hand-held, gas-engine chain saw can be used equally well to cut the logs to length.

Comparing the two basic cross-cut sawing methods, the radial saw offers the advantage of a faster cut with a narrower kerf (less sawdust produced), but it generally must be left running (more energy consumed) between cuts due to a delay in reaching cutting speed (larger diameter, higher inertia). Also, teeth can be chipped off the radial saw if foreign materials are embedded in the bark of the logs. The chain saw will generally only suffer a dulling of the teeth on rocks and it is advantageous for intermittent cutting with a complete shutdown or an idle speed between cuts but the cut is slower than a radial saw.

Once the whole logs have been reduced to an appropriate size (split and/or cross-cut), the next steps can take place. Split logs could be manually or mechanically transferred to a slab-burning furnace (Dutch oven type). If however, a finer, faster-burning fuel is desired, the wood slabs or other coarse-sized biomass must be subjected to a further size reduction.

The kind of size reduction which will allow the biomass to pass through a 5 cm (2 in.) mesh screen requires a class of mechanically powered equipment known as "hogs" (other common names: grinders, shredders, hammer mills, etc.). There are different types of hogs, each designed for specific types of biomass, and they are available in a wide range of sizes, from about 15 kW (20 hp) to as large as 1500 kW (2000 hp). The power rating for a hog is related to the size (diameter) of biomass material that can enter the hog and to the rate at which the material can be hogged. The shredded biomass that leaves the hog is referred to as hogged fuel or, simply, "hog fuel", which is the most common form of biomass fuel used in industrial or utility boilers.

The two most basic types of hogs are the hammer hog and the knife hog. The hammer hog utilizes a cylindrical steel core rotating at high speed, to which are fastened rows of free-swinging "hammers". The rotating core and hammers are enclosed in a heavy steel casing with an opening near the top to allow biomass entry. The principle of shredding is simply a process of continuous, high-speed, hammer-like blows to the biomass as it enters the hog. The broken or torn pieces of biomass leave the hog through a screen at the bottom of the hog; "overs" are repeatedly hammered until small enough to pass the screen.

The hammer hog is very effective as a shredder of most types of wood, friable bark, and brittle materials (e.g., nut shells). Some types of biomass with long, pliable and stringy fibers (e.g., bagasse, cedar bark, straw, etc.), however, are not very amenable to the shredding action of the hammer hog and will generally foul and clog up the device For such fuels the knife hog is virtually mandatory. The knife hog employs a central, rotating core, similar to the hammer hog, but instead of the swinging hammers it has fixed knife edges that shear the biomass fibers. Since no hammering is involved, the knife hog is generally effective in the size reduction of the tough, stringy biomass materials. Consultations with the hog manufacturers or vendors is very important in determining the right kind of hog for the particular biomass involved.

Conveying

The on-site transport of biomass materials can utilize a number of different conveying systems. Almost all systems will fit into one of the following categories:

- o Transfer Deck
- o Belt Conveyor
- o Chain Conveyor
- o Screw Conveyor
- o Elevator
- o Pneumatic

Each system has unique characteristics which are appropriate only to specific functions; and care should be taken to choose only the essential equipment, as not all of the different types are required for a biomass combustion installation.

Transfer Deck. The transfer deck is a system generally used to convey large pieces of rigid material (slabs, lumber, etc.) from one spot to another. It is not at all functional for transporting hog fuel, but it would be excellent for the movement of large quantities of logs, wood slabs, etc., especially to force the wood through a cross-cut saw for length sizing.

The transfer deck is composed of a number of specially formed chains, linked to form an endless loop and riding in steel channels fixed at intervals along a rigid, structural deck top. The multiple chains are driven by sprockets mounted to a common shaft at the exit end of the deck. Idler sprockets or pulleys mounted to a shaft at the other end and an appropriate tension system (usually catenary) complete the cycle. The tops of the links can be chosen for any of several functions: smooth and flat for no-resistance travel, with rollers for lateral displacement, or with cleats to give a gripping effect.

Belt Conveyor. The belt conveyor is a pulley-driven belt of a rubber and fabric, laminated composition. Like the transfer-deck chain, it is also joined into an endless loop. It runs from a head pulley (driven end) to a tail pulley and back again, but there may also be one or more additional pulleys on the return path for belt tension or for a change in the path vertical angle. The two runs of the belt (top and bottom) ride on cylindrical rollers which support the belt and its load in a horizontal position over short spans of typically 1 to 2 meters (3 to 6 feet).

A series of three-roller units are often used to bend the top, or load-carrying, belt run into the shape of a shallow trough, with a side-wall incline not to exceed about 45°. This prevents the shredded biomass from falling over the edges of the belt as it moves. However, if the belt is to carry longer pieces of wood or unshredded bagasse which may occasionally be piled higher than the sides of a three-roller trough, then single rollers and independently supported, vertical, stationary side walls or a full trough of sheet metal can be placed around the belt to prevent a spilling of material.

A belt conveyor can move shredded biomass from one location to another very quickly, at speeds up to 240 m/min (800 ft/min), and they are available in a wide range of widths from about 36 to 210 cm (14 to 84 in). It can also move the biomass fc a considerable distance in a single run, subject only to the limitation of the belt tension required and the resulting tensile stress in the belt material.

The belt conveyor is a very efficient conveying system, in that the use of rollers to support the belt reduces friction and keeps power consumption relatively low. It is very useful for transporting coarse biomass to a hog, hogfuel to a fuel pile, or piled fuel to the furnace loading hopper.

One disadvantage to the belt conveyor is that it is limited to a relatively modest angle of ascent (or descent). Since the only force keeping the fuel on the belt at an incline is friction and because the coefficient of friction of most substances on rubber rarely exceed 0.5, the maximum allowable incline for the belt conveyor is about 27° - - even this angle may be excessive for some very dry materials. Another disadvantage is the exposure of the fuel on the belt to blowing winds and to rainfall. A covering for the conveyor is advisable to help control dust blowing and drift and, especially in the tropics, to keep heavy rainfall from wetting the fuel. A second disadvantage of belt conveyors is that they are a straight line device requiring two belts for each change in direction.

The belt conveyor is the preferred conveying system for almost all biomass fuels, except for very fine and dry materials, when relatively steep angles of incline are not needed. It is also the least expensive system, costing from about $275 to $485 per lineal meter ($85 to $150 per foot) installed in the U.S.

Chain Conveyor. A chain conveyor is generally used when steeper inclines (to 45°) are required or when the biomass is still in the form of long pieces. The chain is driv hv a powered head sprocket and runs freely over an idling tail sprocket or drum. A take- mechanism at the tail sprocket assembly is generally employed for chain tension.

The top half of the endless loop chain will usually ride in a metal trough, and metal wings or "flights" will typically be connected at various intervals to links in the chain. The flights ride along the bottom of the trough to catch and carry the fuel materials up the conveyor to the head sprocket where it falls to a hopper or to another conveyor.

The chain conveyor is very versatile for use with a wide variety of biomass fuels, but it is also quite heavy, requires a strong structural support, and is subject to a lot of wear and maintenance from steel rubbing on steel. The electrical power demand on a chain conveyor is higher than for a belt conveyor and it cannot move the material as quickly. It is, however, very durable, and most of the parts will last a long time.

Due to the extra structural steel requirement and higher fabrication expense of the chain conveyor, it is much more expensive than a belt conveyor of the same capacity, costing from $500 to $1,100 per linear meter, installed in the U. S. And although it can raise materials at a much steeper incline than the belt conveyor, it is not able to convey the same distance as a belt conveyor due to friction, high horsepower requirements, and chain strength limitations.

Screw conveyors are generally of the hollow shaft type with various pitch angles suited to the size of the material being handled. They are basically used for conveying small sized materials such as grains, sawdust, sander dust and other small sized prepared fuels. Screw conveyors are generally only used on large sized materials as metering screws not exceeding 3.6 meters (approx. 12 feet) in length with a screw flight diameter not exceeding 0.6 meters (2 feet). Screw conveyors can be used vertically, inclined or horizontal, however, when inclined or vertical, they are contained inside a tube or pipe. There is no normal rule of thumb for pricing a screw conveyor because there are too many variables involved.

Elevator Conveyors in biomass movement are generally always of the bucket type or vertical screws. Bucket elevators are a series of buckets attached to parallel chains and enclosed in a sheet metal housing. This type of conveyor is used generally only with small size material. Bucket elevators have several limitations such as high maintenance, slow speed and limited capacity. It also is a type of equipment which is difficult to make dust tight. Bucket elevators are generally the most expensive of the conveyors and frequently start at $15,000 (U.S.) and up.

Pneumatic Conveyors. This system conveys materials through circular ducts by floating them in air at high velocities. It is probably the most common system, but wasteful of energy. In a pneumatic system, fine or pulverized materials are fed into a transport duct through screw, star valve, venturi or elbow feeders. The fan is often located upstream from the feeder, but can be located on the other end of the system downstream from a separator. In the former fan location the material is conveyed at pressures above atmospheric; in the latter fan location material is conveyed at pressures below atmospheric.

Pneumatic system friction losses include those due to the sliding of material along the duct walls. There is a minimum transport velocity for each material that will determine the cross sectional area of the duct. The weight flow of material to weight of air ratio is called the "material loading". Generally most biomass material may be conveyed at 15 to 25 meters 50-80 ft per second with the less dense, bulkier materials being conveyable at the lower figure. Wet or sticky materials do not lend themselves to this method of conveyance.

The pressure losses in a pneumatic transport system include those for: lifting the bulk material, accellerating the material initially and re-accellerating it at each elbow, overcoming sliding friction in horizontal runs and friction due to centrifugal force as the material slides around bends. The vertical run loss is proportional to the lift, L, in feet and the horizontal run loss is proportional to horizontal travel, H, in feet. These formula for pressure losses in the air pressure in inches of water relate to pounds of material transported per pound of air.

$$P_L = RL/69.4$$

$$P_A = R(VP)$$

$$P_H = fRH/69.4$$

$$P_{90^o} = \pi fR(VP)$$

$$\text{Total loss} = \sum P_L + P_H + n(P_A + P_{90^o}) + P_A$$

R = material loading in lbs/lb of air, VP = velocity pressure of air in inches equal to $\left(\frac{V}{4005}\right)^2$ in which V is in feet/minute, f = coefficient of friction 0.4 rice to 1.0 sawdust and n = number of bends.

Pneumatic conveyors are often the least expensive in initial cost. The sizes of pipe and equipment are influenced by the bulk density, material loading and distance the material must be transported.

Fuel Drying

Drying is not usually practical unless the energy for drying comes from some untapped energy source external to the combustor and steam generator. The energy required for drying is usually greater than the energy required to vaporize the moisture in the fuel within the furnace, simply because the boiler furnace is a more efficient user of the energy than the dryer device.

Fresh rice straw, some very wet woods, hydraulically removed bark, etc. will not consistently burn without significant quantities of auxiliary fuel. It is beneficial to dry the fuel material either in the collecting, transporting, storage or fuel preparation phases of handling.

An example of drying fuel in the collection phase is drying in the fields/forests by using the sun's energy. During transporting, the heat from the compression of air in pneumatic systems effects some drying. By storing fuels for extended periods under cover where the air can get to it results in significant drying. On the other hand, leaving the biomass in the rain may make it unburnable. Generally, biomass will not burn well if it is over 60% moisture by weight.

The one common method of drying fuel is to use the waste heat in the flue gas from the boiler. If the exhaust temperature from the boiler is high enough, say 450 to 480°K, this heat may be used to dry the fuel in rotary dryers. The three-pass dryer is particularly efficient and effective. Waste heat from any source can be used to dry fuel and ground dried fuel can be fired into the dryer to provide the heat with which to dry fuel.

One hazard of drying fuel is that volatiles are often given off during the drying process that form aerosols that are visible. The pinenes and turpines from wood fuels are objectionable to regulatory authorities in the U. S. and temperatures for drying of less than 480°K are generally required to prevent "blue haze".

Fuel Storage

Fuels are generally stored in the prepared stage ready to be burned. More often than not, this is an incorrect approach. Fuels stored in the open should shed rain, yet be readily available for resizing to burn with little restorage.

Large fuel piles of material sized for firing are like sponges and will soak up water. Such piles should be covered so that the maximum amount of energy can be obtained from the fuel. Sized fuel in piles also has a tendency to spontaneously combust if the piles are not rotated every 4 to 6 months.

Even with the best of designs, fuel piles tend to become enormous. Biomass plants are somewhat restricted in location by these more or less undesirable fuel piles. If any lesson is to be learned here, it is that it is better, in areas where rainfall exceeds about 75 cm/yr, to bring the relatively dry biomass to the processing facility for a period of short or covered storage in the processed form before it is needed (if this option is open to the designer).

ENVIRONMENTAL CONSIDERATIONS

There are many less developed countries subscribing to the USDA/AID program. However, it is beyond the scope of this review to itemize all the existing environmental regulations relating to combustion on a country-by-country basis; such a project could entail several volumes of written information. It is felt, therefore, that the most comprehensive method of presenting the subject of environmental considerations is to describe the major concerns that have evolved in the U. S. and to define the knowledge and experience that have come from dealing with the pollution problems associated with biomass combustion.

Environmental concerns can be generally categorized in terms of three broad areas of impact. These areas tend to coincide with the three physical states of matter, as can be seen in the following list:

- o Air Pollution
- o Water Pollution
- o Solid Waste

A fourth area of recent concern, i.e. endangered species of wildlife, is often linked indirectly to one or more of the three primary concerns as well as to other kinds of activities. Some of the activities surrounding the process of direct combustion of biomass have the potential to endanger certain species of wildlife, if care is not taken. The harvesting and transporting of forest biomass materials, in particular, has a high potential for adverse consequences, but as the means of biomass acquisition are not within the scope of this review, the details will have to be sought elsewhere. The pollution by-products of biomass combustion, however, are immediately recognizable and will be examined.

AIR POLLUTION

Air pollution from biomass combustion is defined as the emission of certain, known, gaseous and solid pollutants, generated in the combustion process and released into the air by the combustion system. The degree of harmfulness to health caused by breathing these pollutants is directly proportional to the amount of concentration in the ambient air, usually expressed in micrograms (of pollutant) per cubic meter of air (ug/m^3), which can be measured at any location by instrumentation.

The ambient concentration of any air pollutant at any time is a function of three factors: the rate of pollution production by the source (a combustion system); the proximity to the source; and the movement of air (wind velocity) in the area of the source. The latter two factors are not subject to control, but the rate of pollution production is controllable.

The rate of production in kilograms per hour (or pounds per hour) is a function of the size (capacity) of the combustion system and of the amount of pollutant concentration in the combustion flue (exhaust) gas. The larger the size of the system and the greater the concentration of pollutants in the flue gas, the higher the rate of pollution production will be.

The capacity of the combustion system can be limited as a means of controlling the increase in ambient pollution concentration; but equipment capacities are usually chosen for other reasons, such as a preferred heat · power output, and reducing size generally means a sacrifice in thermodynamic efficiency.

The most commonly practiced means of reducing air pollution in the U.S. is to control the concentration of pollutants escaping in the flue gas. This can be accomplished in a very limited way by simply controlling the combustion process in order to obtain as clean and smokeless a flame as possible. This has not proven adequate for compliance with recent U.S. air pollution standards. Thus, the use of specially designed, flue-gas cleanup equipment has now become commonplace.

Because the concentration of pollutants in the flue gas can be measured quite accurately at the source (the flue stack) and because the available control equipment has become increasingly effective at reducing some pollutants, environmental enforcement agencies have concentrated on requiring tighter and tighter air pollution controls on combustion equipment. Limits have been set for each major class of pollutants, although these tend to vary by specific location; controls generally have to be more stringent near the cities (where a large number of polluting sources already exist) and are somewhat more relaxed in remote or rural areas.

The flue gas concentration limits are specific to each designated pollutant, as some are considered more harmful than others. The major, identified pollutants arising from biomass combustion are listed below:

- o Particulate
- o Sulfur Dioxide
- o Nitrogen Oxides
- o Hydrocarbons & Carbon Monoxide

The limits of concentration of each identified pollutant in the combustion flue gas have been set in the form of guidelines by the U.S. Environmental Protection Agency (EPA). The quantities specified for each limit are precisely enumerated; but they are enforced by local authorities (state or county agencies) with varying degrees of flexibility on a case-by-case basis, influenced by the existing pollution problems, meteorological conditions and economic needs of each city and state. Therefore, it is not the purpose of this review to imply that the limits set by the U.S. EPA must be followed by all the countries of the world. The limits will be noted to show what is technologically feasible and the relative costs involved. Each country will have to assess its own conditions and needs to determine what is reasonable and practicable.

Particulate

Particulate is solid matter that is so finely divided (into "particles") that it is entrained and lifted up by air movements and gas streams. All types of biomass contain small amounts of mineral (ash); North American wood fuels typically have ash contents between 0.2% and 2.0% by weight, depending on the species. If soils have adhered to the wood surface, then the total ash content can be slightly higher.

As the ash cannot be converted to a gas by the combustion process, it will either remain at the bottom of the combustion chamber (bottom or grate ash) or be entrained upwards as dust (flyash) by the hot combustion gas. In addition, if the biomass fuel is in agitation (a hot fire and high combustion air velocity) or if it enters the chamber in a finely ground state, small particles of unburned fuel or char may also be carried up with the flue gas. These unburned particles add to the total flyash.

Some combustion systems, such as boilers, have sections where a change in the flue-gas velocity will cause the larger and heavier particles of flyash to drop out into collecting bins or hoppers. That which does not drop out is the particulate or fine dust (100 to 0.1 or less microns in diameter); and if left untreated, it will exit with the flue gas into the atmosphere. The smaller particles (below 1 micron) may float in the air for days before settling.

The health hazard from particulate is the result of inhalation of the finer dust and its accumulation in the lungs, which may lead in time to respiratory disease. And the greater the ambient concentration of particulate in the air, the greater the probability that more of it will be accumulated in the lungs in a shorter period of time.

Standards. It is difficult to accurately correlate the magnitude of ambient particulate concentration with the degree of hazard to health; and of course it is impossible to reduce the concentration to zero as many types of sources are constantly adding to the load (automobile traffic, agricultural cultivation, duststorms, etc.). Nevertheless, the U.S. EPA has set standards for allowable ambient concentrations of particulate in the air. There is a Primary Standard and a Secondary Standard, which are goals to be achieved by every populated community in the U.S. presently exceeding either standard.

The Secondary Standard is exceeded if the annual geometric mean of particulate concentration exceeds 60 ug/m^3 (micrograms per cubic meter). The Primary Standard is exceeded if the mean is above 75 ug/m^3. There are also 24-Hour Primary and Secondary Standards; these are limits of 260 ug/m^3 and 150 ug/m^3, respectively, not to be exceeded more than once per year.

In order to achieve these goals in all U.S. cities, the individual states have set up programs within the EPA guidelines to curtail and limit the amount of particulate that can be emitted by industrial sources. Industries using coal or biomass combustion systems are generally targeted as major contributors to the particulate problem.

Emission Limits. The method that was set up to reduce the industrial contribution to the overall pollution problem was to impose another class of standards, or limits, on the concentration of pollutants emitted from industrial sources. In the case of biomass (wood bark, bagasse, etc.) combustion sources, the uncontrolled particulate emission may range between 4.6 and 13.7g $/m^3$ (2 and 6 gr/ft^{3*}) of exhaust (flue) gas, and the flue gas may have an opacity (light filtering) rating of from 40% to 80% or more, depending on the system of combustion, the fuel characteristics and the control of combustion air. Suspension burning tends to produce more particulate emission, pile or grate burning less.

The goal behind the emission limits on particulate is to enforce the use of control equipment on the combustion flue gas to reduce the particulate to a much lower concentration. The earliest and least expensive equipment used to reduce particulate emissions is a mechanical separator (a "cyclone") using the centrifugal force of cyclonic gas movement to separate the heavier mass of the particles from the lighter mass of the flue gas. The particulate laden flue gas is forced to enter a cylindrical vessel tangentially, so that a cyclonic movement of the gas throws the heavier particles to the walls where they spiral downward by gravity to a collection hopper as solid waste. The gas and smaller (lighter) particles can escape only by spiralling back upward through a central duct and to a stack that allows them to exit to the atmosphere. For greater efficiency in handling the large volumes of flue gas generated by

*Actually gr/SCF - grains per Standard Cubic Foot; a SCF is an amount of gas occupying one cubic foot when free of water vapor and at standard conditions of temperature and pressure (25°C and 1 atmosphere at sea level).

combustion a number of cyclone tubes or cylinders are placed in parallel combinations to aid in particulate removal, thus giving rise to the expression "multi-clone".

The mechanical-type collector is fairly efficient in removing the larger particles (above 40 microns in size) and does not demand very much energy for operation. It is, however, very inefficient in separating the smaller particles, and if the biomass combustion system produces a lot of particulate in the low size range (e.g., flyash reinjection or suspension burning is used), a large amount of particulate will pass through the collector and enter the atmosphere. Depending on the fuel quality and the combustion system, the mechanical collector is capable of reducing the particulate emission at the stack down to a range of about 2.3 to 0.46 g/m^3 (1.0 to 0.2 gr/ft^3), and opacity ratings will typically be from 40% to 20%. At an efficiency of particulate collection which rarely exceeds 80%, an uncontrolled particulate emission of 20 kg/tonne (40 lb/ton) of fuel burned* can be reduced to about 4.0 kg/tonne (8 lb/ton) of fuel by a mechanical collector. By multiplying this factor times the expected number of tonnes (tons) of fuel to be burned in a year, one can estimate the annual number of kilograms (pounds) released to the atmosphere by this type of control equipment.

The mechanical collector is now considered inadequate by U.S. environmental authorities, and particulate emission limits have been gradually and progressively reduced below 0.46 g/m^3 (0.2 gr/ft^3) to 0.23 g/m^3 (0.1 gr/ft^3) and, most recently, to 0.11 g/m^3 (0.05 gr/ft^3) for new, wood-fired boilers. These limits have rendered the use of solely a mechanical collector

*An EPA tested average for boilers firing bark and wood/bark mixtures.

quite insufficient, and more efficient collection equipment has to be obtained in order to achieve compliance with the newer regulations.

One device which has the capability to reduce particulate emissions down to the range of the current limits is the wet scrubber. It costs more than the mechanical collector in both capital and operating expense, but it removes particulate from flue gas much more efficiently. The wet scrubber operates on the principle of the flue gas impinging on a water spray, such that a high degree of contact and mixture of gas and water is achieved. The result is that most of the particulate in the gas either dissolves or goes into suspension in the water, and the mixture is removed as a thin sludge or slurry.

The most advanced wet scrubbers use a venturi system, either with parallel rods or a narrow throat, to gain the maximum gas/water contact and mixing effect with a minimum contact area and unit size. The use of venturis, however, increases the gas pressure drop across the system in order to work effectively and, thereby, increases the demand for fan power which raises the capital cost and operating expense. In some models the venturi system is adjustable, so that the particulate emission limit can be achieved but not at the expense of an over-designed power drain from the system. Wet scrubbers can reduce opacity to about 10%.

Wet scrubbers can typically reduce particulate to 0.23 g/m^3 (0.1 gr/ft^3) or less. Some of the better ones can lower the particulate to 0.11 or 0.09 g/m^3 (0.05 or 0.04 gr/ft^3), but only a few manufacturers will guarantee such numbers. Connecting a wet scrubber in series with, and downstream from, a mechanical collector can help the overall efficiency somewhat, as the mechanical system knocks out the larger particles and helps reduce the load on the scrubber; but firm data for comparing the actual improvement in efficiency is not available.

Another concept which has developed in the U.S. environmental picture is that of the Non-attainment Area. This term applies to those geographical areas (usually industrial cities) where either the EPA Primary or Secondary Standard for ambient pollutant concentration is not being met. Within Non-attainment Areas new industrial pollution sources, and sometimes even existing sources, are required to design for the lowest achievable emission limit. In terms of particulate control this translates to between 0.023 and 0.046 g/m^3 (0.01 to 0.02 gr/ft^3). The theory behind this is that only by achieving a drastic roll-back on a group of major pollution sources can the Non-attainment Area reach attainment status.

There are only a couple of types of technology which can approach these lowest limits. One is the electrostatic precipitator (ESP) which uses an electric charge of high voltage to ionize particles that are attracted to plates of the opposite charge. The other is referred to as a "baghouse" or a fabric filtering system. Both are quite effective in removing particulate at efficiencies of 99% or better. But both cost many times more than either the mechanical collector or the wet scrubber. They also may draw a heavier power load than either of the two simpler systems. They will, however, reduce opacity to practically zero.

A serious disadvantage to the use of an ESP for control of wood combustion particulate is that the particles do not always ionize sufficiently, unless there is a precise amount of moisture in the flue gas or unless another gas to aid the ionization process is added. A disadvantage to the baghouse is that, unless the flue gas is kept below a temperature limit and all sparks are eliminated, there is a danger of material on the fabric catching on fire and burning up. And a heat-resistant fabric will add even more to the cost of the unit. In addition, if there is any salt in the wood (or other biomass), the salt usually carries over into the flue gas and can clog or "blind" the fabric of the bags to any further passage of gas.

An ESP or a baghouse should probably not be considered for particulate control on biomass combustion unless the site chosen for the combustion system is within a zone or area of existing high particulate concentration. Because, aside from the operational and maintenance problems and higher power cost, these two systems have an extremely high initial cost.

The capital costs of the various types of control equipment to remove particulate can be roughly estimated in terms of price ranges per unit-volume flow rate of flue gas. The flow rate of the gas is approximately proportional to the size of the combustion system and can be estimated on the basis of the rate of biomass fuel consumed, the amount of excess combustion air and the chemical analysis of the fuel etc.

The cost multipliers for mechanical collectors are the lowest and range between \$18 and \$35 (1980 U.S. dollars) per m^3/min (\$0.50 to \$1.00 per cfm) delivered and erected in the U.S. Wet scrubbers are almost twice as expensive, running from \$35 to \$71 per m^3/min (\$1.00 to \$2.00 per cfm). The prices for ESP's and baghouses are much higher. Precipitators will range between \$280 and \$710 per m^3/min (\$8 to \$20 per cfm), starting with the lower cost, wet ESP's and moving to the dry systems. Baghouses are priced very nearly the same as precipitators, from \$350 to about \$710 per m^3/min. These cost ranges for each category of control equipment reflect slightly different levels of efficiency, special design features, and varying shipping and installation costs. The cost ranges are not sufficient for design estimates but are intended primarily to show the relative differences in cost for control equipment.

Sulfur Oxides

There is generally very little sulfur in most types of biomass. U. S. wood species contain less than 0.1% sulfur by weight. Assuming the possibility of an average of 0.05% sulfur in the biomass fuel, there could be theoretically 1.0 kg/tonne (2.0 lb/ton) of fuel burned emitted as various oxides of sulfur (primarily SO_2). This may not seem like much, but when it is considered that even the smallest combustion systems may consume about 8,000 tonnes (9,000 tons) of fuel annually, as much as 8,000 kg (18,000 lb) of SO_2 could be released to the atmosphere per year.

The harmful effect of sulfur oxides is that in their contact with water they form corrosive acids (sulfurous, sulfuric acid, etc.). These acids can be formed directly on contact with the moisture of the mucous membranes of the body; if prolonged exposure to high enough concentrations is endured, physical damage to body tissues (eyes, nose, mouth and lungs) and to general health will result.

Although SO_2 is the usual combustion product, it can further oxidize to SO_3 in the atmosphere; SO_3 is a constituent of highly corrosive sulfuric acid (H_2SO_4) which is formed in the presence of water (rain). "Acid rain" is not directly harmful to health unless it gets into drinking water in large concentrations, which is not usual. Concentrations of SO_3 in the air, however, can be very damaging to leafy crops, such as lettuce.

SO_2 generally does not become a problem except in areas where large quantities of coal (higher sulfur content than biomass) are being burned and where air movement tends to become stagnant. However, the combustion of very large quantities of biomass (or a number of combustion sources in close proximity) in stagnant air conditions could possibly cause an SO_2 pollution problem. The EPA has set the Primary Standard for Sulfur Oxides (SO_2) at a limit of 80 ug/m^3 of ambient air, annual arithmetic mean. Only the most heavily industrialized cities in the U.S., which burn huge quantities of coal, coke or other fossil fuels, exceed this standard.

SO_2 is a gas, so it cannot be separated from the flue gas by mechanical, precipitation or filtration collectors. It has, however, a natural affinity for water, so a wet scrubber is the only technically practicable system for removing SO_2 from the gas stream. If a wet scrubber is used to remove particulate from a biomass combustion system, the potential for SO_2 pollution is virtually eliminated.

The EPA has set no limits to the allowable concentration of SO_2 in the flue gas from bark and wood-fired combustion systems in the U.S. Therefore, a wet scrubber cannot be recommended for pollution control if its sole purpose is to remove SO_2. A specific analysis of the actual biomass fuel (sulfur content), of the local meteorological conditions and of national air pollution regulations concerning SO_2 is needed to determine if SO_2 should be controlled.

Nitrogen Oxides

Nitrogen oxides (primarily NO_2) are formed in all combustion systems using air as the oxidizer, due to the presence of nitrogen in the air and to the generally high temperatures of combustion. The formation of NO_2 is proportional to the combustion temperature, which in turn is proportional to the rate and completeness of the combustion process. If the fuel is burned fast and cleanly, (i.e., little "smoke") the fire will be hotter and more NO_2 will be produced; if the fuel burns slowly and produces smoke, less NO_2 will form but more hydrocarbons will escape. And since the loss of hydrocarbon represents a loss of fuel energy, it is thermodynamically preferable to burn the fuel as completely as possible and as hot as practicable.

The only pollution problem caused by NO_2 is that when mixed with hydrocarbons in the atmosphere it leads to the formation of photochemical oxidants (principally ozone), otherwise referred to as "smog". Breathing excessive concentrations of photochemical oxidants is irritating to the eyes and other mucous membranes; but if little or no hydrocarbons are in the ambient air to combine with the NO2, no appreciable amount of oxidants will be produced.

NO_2 by itself and in small concentrations in air is essentially harmless. The EPA has set a Primary Standard for NO_2 with a limit of 100 ug/m^3 of ambient air, arithmetic annual mean; but it is rarely enforced because there is no practical way to remove NO_2 from flue gas.

Hydrocarbons and Carbon Monoxide

Hydrocarbons (HC) and carbon monoxide (CO) can be classed together as unburned, fuel by-products of combustion, resulting from an incomplete combustion process. As stated previously, a mixture of HC and NO_2 in air lead to the formation of ozone, a major pollutant. CO is a gaseous fuel that can be further oxidized to CO_2, and it is only harmful to health in very high concentrations (EPA Primary Standard is 10 mg/m^3 of ambient air, maximum 8 hour average, once per year).

Condensible hydrocarbons can be removed from flue gas by a wet scrubber; volatile hydrocarbons and CO cannot be practically controlled by any "back-end" systems. The logical and most economical means for controlling HC and CO is to take steps to ensure complete combustion of the biomass fuel. This can be accomplished by keeping the fuel as dry as possible (wet fuel burns more slowly) and by providing sufficient overfire air to ensure the complete combustion of all the gaseous hydrocarbons and CO. Complete combustion eliminates HC and CO as a pollution problem.

WATER POLLUTION

The concern with water pollution is the effect it may have on the quality of two valuable natural resources: subsurface ground water (well water) and natural bodies of surface water (lakes, rivers, streams). Ground water may be used for human consumption and/or for crop irrigation. Surface water may also be used for human consumption and irrigation; but, in addition, it is also the natural habitat of fishes and amphibians and a source of drinking water for some mammals and reptiles. In either case the maintenance of uncontaminated, natural sources of water is not only beneficial but also vital to human health and to the preservation of numerous animal species.

Combustion systems and/or their ancillary components have the potential to contribute to water pollution in ground and surface waters. The three major sources of water pollution stemming from the operation of a combustion system are the following:

- o Fuel Pile Leachate
- o Ash Leachate
- o Sanitary Sewage

These three are distinctly different categories of water polluting sources and should be handled and treated separately.

Fuel Pile Leachate

It is very common to have a fuel storage pile near a combustion system, and it is also a common practice in the U.S. to have the fuel ground or hogged to an appropriate size for combustion prior to pile storage. However, many types of biomass residues (wood, bark, bagasse, etc.) contain significant quantities of plant sugars, and these sugars are quite soluble in water.

If rain should fall on the pile either continuously or intermittently for a period of several weeks or more, the water draining down through the pile will leach the sugar from the biomass. And the process of sugar leaching is aided by having the biomass ground into small pieces. Then, if the rainfall continues, the water runoff from the pile will carry the sugars to the nearest drainage system and ultimately to a natural body of water, such as a river, stream or lake.

The hazard that is caused by sugars and other carbohydrates entering a natural waterway is that they are substances which create a Biochemical Oxygen Demand (BOD) on the body of water. In the process of biological decomposition of the BOD substances oxygen is drawn from the water, and the speed of the process is proportional to the temperature of the water. The result is that, if a sufficient quantity of BOD is present, the oxygen content of the water will drop below the level needed to sustain aquatic life. Migratory, spawning fish and game species would be the first to die, and if oxygen content dropped still lower, even the food fish and slow-moving bottom feeders could asphyxiate.

There are several ways to avoid BOD contamination of a water body due to leachates from a fuel pile. One is to build a covering roof or open-sided shed to keep rain from making contact with the fuel and draining the uncontaminated water away by underground piping. This method, however, could be very expensive, as the fuel storage requirements could demand a very large area. Another method is to avoid grinding or hogging the biomass until it is actually time for combustion. This may not be convenient, however, as the purpose of a fuel pile allows for grinding equipment breakdown and occasional surges in heat or steam demand.

A third alternative to the problem of high BOD-content leachates entering the surface water is to provide catch basins for the runoff and pipe the contaminated water to a holding pond. In the pond the bacterial action will oxidize the sugars and subsequently lower the oxygen content, but air movement over the surface of the pond will eventually restore the oxygen content of the water by the time the water is released from the pond to the stream or river. The pond should not be much over 1.0 meter (3.28 ft.) in depth, and the length of holding time will vary with the time for BOD to be oxidized and oxygen to be replenished (a function of average ambient temperature and wind velocity). A dual pond system may be needed to provide adequate working time in one while the other is filling.

Not all biomass residues contain sugars (e.g., grain husks and nut shells) and not all combustion systems and fuel piles will be large enough to cause a BOD pollution problem, especially if the nearest water body is large in size by comparison. But leachates from fuel piles is a problem that should be considered at all times. Only testing and monitoring of downstream water quality will determine if BOD is becoming a hazard.

A Primary Standard of BOD treatment for water effluent has been set by the EPA at a limit of 150 ppm (parts per million). This is adequate for discharge into very large rivers, bays and oceans. A Secondary Standard limit of 30 ppm is more appropriate to smaller rivers, streams and lakes. These limits can be used as guidelines for applications in other countries, but only careful monitoring can prevent the destruction of fish populations for each particular application.

Ash Leachates

All biomass combustion systems produce an ash residue. Some of the ash will collect on the floor or below the grate of the combustion chamber (bottom ash). Flyash will be picked up at hoppers below the economizer and/or air heater of most boilers and by the application of air pollution control equipment. Since ash contents in the biomass may range up to as much as 2% by weight, for every 1 tonne (1.1 ton) of fuel burned as much as 20 kg (44.1 lb) of ash may be collected. This will eventually accumulate into a large quantity of ash.

The problem with ash leachates occurs when the ash is placed in an open pile where rain-water can make contact or when water is added to the ash intentionally to prevent blow-away or fugitive dust escape. The ash contains high concentrations of sodium (Na) and potassium (K) compounds (salts) which are very soluble in water. If an excess amount of water washes the ash and drains from the site, it will eventually reach a natural body of surface water or even subsurface ground water. When this happens, the saline content of the water is raised and the water becomes degraded for purposes of drinking or for freshwater, aquatic wildlife.

The standards set in the U. S. generally prohibit the raising of Na and K ion concentrations above 1 ppm in freshwater downstream from the discharge area. Ash leachates, however, cannot be practically t. ated to remove salts, so the goal should be to achieve zero discharge of ash-contaminated water. This can be accomplished by not allowing the ash to be wetted more than just enough to eliminate the dust problem. Regular and periodic disposal of the ash in a properly sited, earth-fill, disposal area will eliminate any problems from ash leachate.

If a boiler and turbine are part of the biomass energy conversion system, there will be an additional problem to avoid salt compounds from entering fresh water. However, all of the various plant water purges and blowdowns (boiler, demineralizer, cooling tower wet scrubber, etc.) can be utilized in an order of progressive degradation until the final effluent is mixed with the ash to form a sludge which can be hauled to a safe disposal site. In this manner the zero discharge of salt-contaminated water to a stream can be achieved.

Sanitary Sewage

If there is a number of personnel employed to keep the combustion system operating, sanitary waste should be handled in a way that will eliminate the health hazards caused by its entry into ground or surface water sources of human consumption. This can be achieved by the construction of a septic tank and a drain field for the septic tank effluent. Care should be taken to choose a site for the drain field where tests indicate the soils will percolate adequately.

If a centralized sewage treatment plant (municipal) already exists at a nearby location, piping the sewage to the treatment plant may prove to be a reasonable alternative to a septic tank/drain field. In such cases it is inadviseable to construct a special treatment plant solely for the use of the personnel operating the combustion system.

SOLID WASTE

The bulk of the solid waste produced by a biomass combustion system is ash. Over a period of weeks or months of continuous operation it will amount to a very large volume of material. Therefore, it is advisable to dispose of it on a regular and periodic basis so that it does not become a problem.

There is nothing particularly hazardous about the ash solely as solid waste, but if it is not handled properly it can be a source of air pollution (fugitive dust) and/or water pollution (leachates). The method commonly used to eliminate these problems is to wet the ash just enough to hold it together as a sludge to prevent dust blow-away but not so much that excess water drains from the ash as it is hauled away.

There is no firm consensus among either manufacturers or combustion system operators as to the best way to collect and handle the ash prior to disposal. Several types of equipment systems for ash handling are available. There is a dry ash collection system that transports the ash pneumatically from the respective collection hoppers (e.g., grate, grate siftings, economizer/air-heater, mechanical collector, etc.) to a centralized storage bin and water conditioning device. This system, however, has the potential for fires and/or explosion due to char content in the ash, and combustion flue gas (low oxygen) is often used as the pneumatic medium to reduce this hazard. Another system employs the hydraulic sluicing of ash from the collection hoppers to a holding pond or to a storage-tank clarifier/evaporator. A large amount of contaminated water is produced by this system, however, and that poses an additional problem in water disposal by evaporation or by recycling.

A third system which is beginning to gain favor in the U. S. involves the use of water-filled drag tanks below the ash collection hoppers. The ash drops from the hoppers into the water of the drag tank, mixes and settles to the bottom to form a wet sludge; and a slow-moving chain conveyor sweeps the bottom and carries the sludge up a water-draining incline into a truck loading bin. This system has the following advantages over the others: fire hazard is not a problem; it does not require large quantities of water; and with biomass-fired boilers it provides a place to dispose of unwanted blowdown water as a wetting medium for the ash.

Regardless of the system chosen, the ash should be wetted enough to be hauled off in open trucks without having dust blow-away and yet not so wet that it drains from the truck in transit. The ideal disposal site is a planned land-fill area where consideration has been given to the potential for ash leachates entering a potable water source. An alternative to land-filling would be to spread the ash thinly over agricultural land as a soil conditioner and mineral fertilizer. Care must be taken with this method, however, as too high a concentration of ash in the soil may actually hinder plant growth. But under properly controlled deposition of the ash on the soil the agricultural disposal of biomass ash has been successful in some cases.

LESS DEVELOPED COUNTRY APPLICATIONS

The ability to design or select the proper direct combustion system to be used in a less developed country depends on many factors; such as, climate, ability to finance and maintain the power plant, acceptance of the purpose for the energy, conflicting needs for the biomass (food vs. energy), etc.

In preparing this discussion it will be assumed that a sophisticated state-of-the-art application will generally be applied in the wealthy nations who can be expected to provide the instrumentation and development effort in the field to "fine tune" such a system. For the less wealthy nations, the more time proven, less energy intensive, more labor intensive applications will be discussed.

BIOMASS ACQUISITION, PREPARATION AND FIRING

The methods of collecting different types of biomass will vary with the type of crop, the type of mechanization available, the beasts of burden available and the agricultural and forestry practices used in harvesting. Certain types and classes of biomass fall into categories that can best be described by the harvesting of the particular crop. Generally the dryer and heavier forms of biomass have the ability to produce more heat per volume and make the best fuels.

If we assume that the biomass is dry or relatively dry and available in some form of a pile in a clearing or field, we can then attack the problem of collecting the material and preparing it for firing in a steam generator.

Straws

Barley, corn stalks, hay, rice, oats, wheat, etc. straws may be used to fire a biomass burning steam generator. Assuming materials are field dried, one way of handling to prepare the material for transport is to bale the straw and load it on trucks, trailers or carts. The straw bales are then taken to the power plant site where the bales are stored under a plastic cover to shed rain. When needed, the bales are broken by a bale breaker, fed into a hog and ground to 2-2.4 mm size for firing. The hogged straw material is pneumatically conveyed from the hog to a cyclonic separator where the transport air is cleaned in a baghouse and the straw particles are temporarily stored in surge bins. When the boiler calls for fuel, screw feeders in the surge bin meter the fuel into a blow pipe where the primary combustion air is added to become the transport air for the straw fuel as it is pneumatically conducted to the suspension burner. The fuel ignites from a gas pilot flame as it enters the furnace and burns quickly. Dried straw material can be fed into conventional oil or gas boilers with few modifications providing the air pollution particulate regulations are not too stringent. Figure 4-1 shows a flow diagram of the suspension burning system just described.

Wetter straw can be burned in Dutch ovens or Fluidized Beds with little or no preparation, but the problems inherent with the poorer combustion and excess air control of the Dutch oven and the parasitic power required by the air supply to the fluidized bed makes these systems seem less attractive because they are generally less efficient (overall).

Suspension firing systems require that fuels be no more than 15% moisture by weight.

Many grain stalks are wetter than this and require drying before burning and to prevent spoilage in storage. Since the combustor must be fed fuel all year around, the prime fuels must be storable. Drying by using suspension-fired, dry-biomass dryers is a possibility, but generally such predrying is expensive in capital and operating cost and generally less efficient than immediate grate firing of the biomass, if that option is open, even for a limited period. Corn stover is probably a poor candidate for a biomass fuel because of the necessity to dry it in many areas where it is produced in quantity in the U.S. This doesn't mean that the corn stalks couldn't be used in other climates where they naturally dry completely.

Canes

Bagasse and Sorghum waste from milling operations is usually pressed, macerated fiber that contains about 55% moisture by weight. About 5% is made up of residual sugars and ash. In their natural habitats the sugar cane appears to be harvested over a much longer period of the year than does sorghum, therefore, farming experience related to when crops are harvested and how many crops per year are planted would be very important to the designer.

The sugar refining process usually crushes the canes into a fiberous sheathe that can be quite long or very short in length. These materials are usually burned at the mill to produce steam used in the sugar refining processes. The storage of bagasse prior to burning is unknown to the writer, but it is presumed to be a continuous process where the waste material is burned as it is produced. Some of the older mills pile burn bagasse without sizing in Dutch Oven; others use a spreader stoker and grate fire the material.

Grate firing requires that the bagasse be conveyed to a hog on a chain or belt conveyor, hogged to 3 inch or less size and screened to prevent larger material from entering the fuel feeding system.

Husks, Pits and Shells

Husks, pits and shells make exceptionally good fuels. Husks are associated with rice and not present on any other mechanically threshed grain known to the writers. The pits and shells are like wood and rather easily burned if prepared for the appropriate method of firing.

Husks are bulky and very light when dry. If they are to be suspension fired then the moisture content must be less than 14%. Milling operations will probably dictate the moisture content of the husk. The husks are rejected during milling. The processing of rice more or less continues year around so the storage piles at a facility that has the ability to burn the husks will be small.

Where the milling has been done at an outlying facility, rice husk piles are large and subject to absorption of moisture from rain. Peletizing of rice hulls using a densification process that supplies an adequate binder would be appropriate because dry hulls weigh about 80-140 kg/m^3 (a large 15 unit chip truck could carry only 9 tons of husks or it would take 3 truckloads to hold the equivalent of 1 truckload of wood chips).

A further problem with rice hulls and the straw is that its silicon content is so high, perhaps 12%. Not only does the silicon content reduce the amount of carbon and hydrogen heat producing elements in the fuel, but the silicon produces a low fusion temperature ash that can form on boiler tubes insulating the steam from the furnace heat.

Again the shells and pits are just like wood fiber; they must be reduced to a size that can be stoker fired on the grate or reduced further in size and dried so that they may be suspension fired. The number of pounds of wet fuel (55% moisture) and the number of pounds of dry fuel (8% moisture) to produce 1 kw of electricity are very roughly 4 lbs and 2 lbs, respectively. To produce 1 MWh of electricity (roughly) requires a ton of dry fuel or 2 tons of wet fuel. To operate a power plant, year around, takes a lot of husks, pits and shells. Generally only one type of fuel may be fired at any one time. Storage and fuel handling systems will, therefore, be much like those of the wood fuels and probably very large in size because of the seasonal maturing of the crop and the necessity to store pits or shells for 12 months of the year.

Bamboo

There are many different kinds of bamboo that range in size from 1 cm to 40 cm in diameter and in all lengths to about 40 meters tall. Bamboo must be over 3 years old to have a firm dry structure. Culms generally live between 5 to 12 years.

The most interesting facet about bamboo is that it does not grow well in poor or swampy soils, yet the production of woody fiber in terms of biomass exceeds that of the temperate pine and hardwood forests. Whole tree chipping appears practical where stalks are cut 25 cm above ground by a slowly moving chiipper that runs over the surface wherever the soil can support a 60 kPa load.

Selective cutting and delimbing of mature culms could be accomplished with a large labor force floated down river to the point of use, hauled out and cold decked until natural drying took place in 7-9 months under plastic covers.

The preparation and firing would be similar to other wood fuels where the material could be ground to 5-10 cm minus particles and stoker fired on a grate or pulverized to 2 mm size and suspension fired.

Wood

The most productive biomass fuel is wood because there is more of it and it can be obtained for extended periods throughout the year, thereby reducing the necessity for large storage facilities. An illustration of a mechanized system is shown in Figure 4-2. Not all phases of the operation need to be mechanized for an LDC application but the stocker conveyors, hogs, splitters and saws should be. An explanation of processing wood residues from the forests in the hogged, pieces (stumps and limbs) and log forms is shown and described. Wood residue in trucks or carts proceed to the scales for weighing, the basis for both payment and inventory control. Roundwood loads are either dumped near the transfer deck or placed on a cold deck. Small or rotted chunks not suitable for decking are either hogged immediately or sent to the stock piles.

Roundwood is transferred to the hog for processing, either from decked inventory or directly from the woods. The material after it is hogged is conveyed to a covered hog fuel storage and handling area. From here the hog fuel will feed directly to the reclaim hopper and then to the boiler. Surplus hogged fuel will be piled outside the covered area.

The hog fuel pile at maximum storage may be about 12 meters high. To prevent fires and spontaneous combustion all inventories should be turned on a regular basis. Hog fuel should not be kept in the pile for more than six months at maximum, and less where possible. Logs, chunks and other residue should also be used as soon as possible.

Some of the small chunks, crooked trunks and stumps may be stored in "stick-piled" windrows roughly 12 meters high and 30 to 40 meters long. Stick-piling is used when the hog is operating at capacity and/or when the covered hog fuel handling area is near full capacity. To maintain a lower moisture content in the wet seasons, it is more preferable to stockpile the chunk wood, rather than process it to hogfuel - a size that would absorb rainwater more rapidly.

Fuel logs, unlike those that enter sawmills, chip plants or other facilities, will be more prone to contain rocks that may cause process units to break down. This happens because the logs are neither debarked nor end-trimmed to eliminate embedded materials. Screens, traps, etc. may be employed to divert not only loose rocks but also wood fines from the hammer hog.

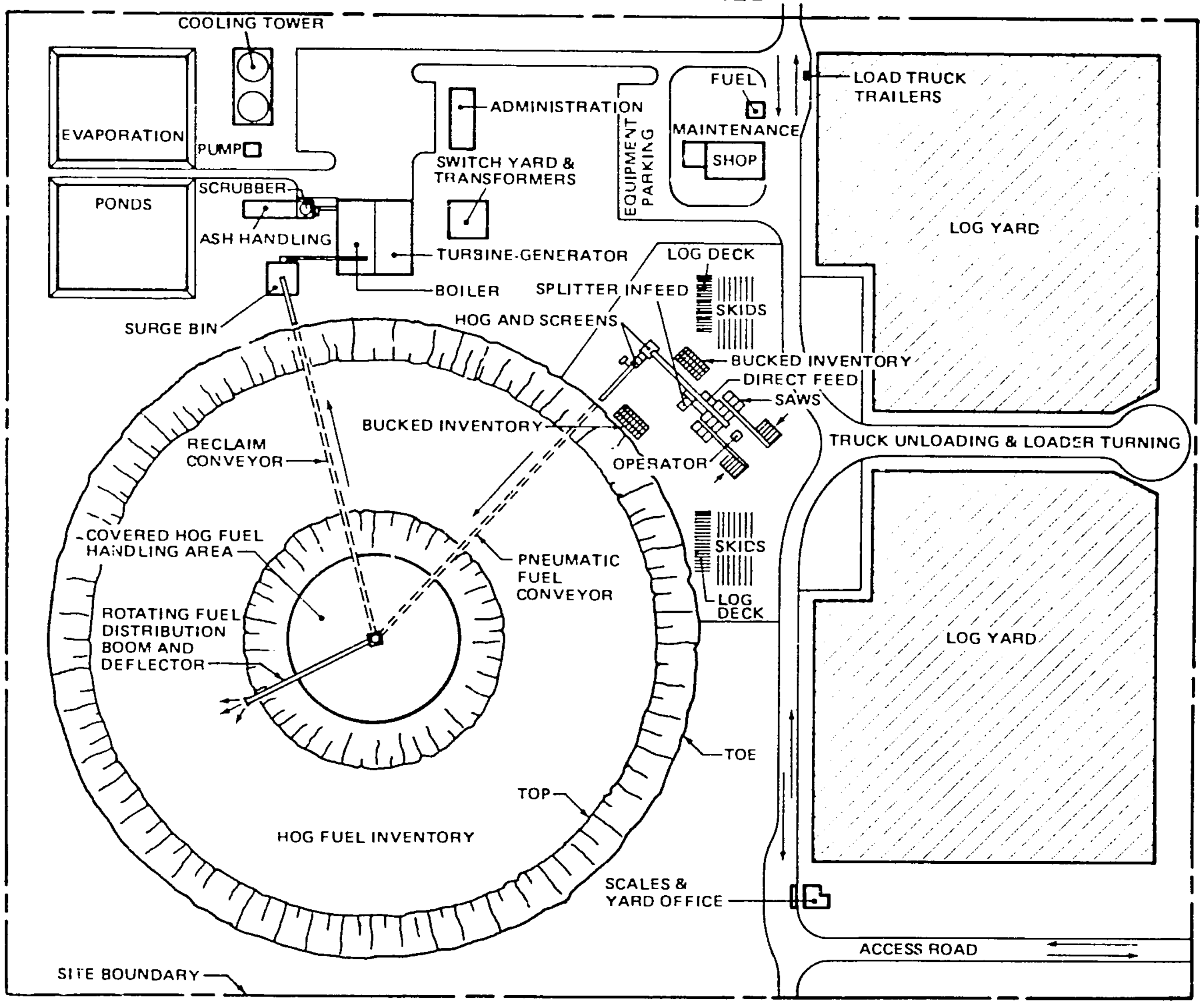
The hog fuel pile should be managed in a manner that will allow first in-first out rotation. As roundwood inventories vary with timber harvest factors occurring in the woods, the amount of hog fuel on the pile will vary seasonally.

The columns of the fuel storage shed will be a hindrance to the mobility of the dozer or back-hoe/front-end loader used to move the hog fuel into the reclaim hoppers. The spacing between bays should be as great as economically feasible. Before any material is stockpiled, the ground should be prepared to provide proper drainage. Ready access around the pile is necessary for both fire protection and logistics in general. The hog fuel conveyors are movable due to their segmented construction and can be used to aid the dozer in extending the storage area perimeter. The hog fuel removal from the covered handling area is by a drag-chain reclaim conveyor that will take the fuel from the hopper to the boiler building. The reclaim conveyor can be situated to pass over the front of the boiler and to dump onto a return conveyor that flows in the opposite direction. Holes in the bottom of the return conveyor allows proportioning of the hog fuel into the hoppers of the fuel feeders to the boiler. The excess fuel that cannot be accommodated by the hoppers returns to the covered handling area.

A slightly different concept is shown in the circular storage pile system shown in Figure 4-3. Here the bent logs, snags, stumps and windfelled trees are not used. Roundwood is sawed to about 2 meter lengths, split if very large and fed to a hog. The hogged fuel is pneumatically conveyed to a rotating boom that distributes the fuel to a pile. The hogged fuel is pushed into a reclaim conveyor for transport to a surge bin where fuel is fed by chain conveyor to the boilers.

Figure 4-3

CIRCULAR STORAGE PILE



DENSIFICATION

Light bulky materials cannot be burned in a grate unless the fuel is densified. Densification has several advantages: (1) there is a saving in hauling costs, (2) the material can be economically stored in silos or buildings, (3) the densification process drys the biomass (when it is burned the heating value of the material by weight is about 2/3 that of coal) and (4) the material can be fired in coal fired boilers.

Many types of biomass can be densified, such as sawdust, brush, stover, straws and other agricultural crops. The densification process saps about 3 to 7% of the available energy from the fuel but this may or may not be partially recoverable because of the drying that takes place in the preparation process.

Most materials are pulverized prior to densifying. Densification techniques employ a mechanism by which biomass attains a high density or "self-bonding". The lignin can be thought of as a sort of a glue which holds the cellulose portion of the fibre together when it begins to soften at about 100°C. Water is used to densify the feedstock. A moisture content of about 10% to 25% is optimal. When the feedstock is heated from 50°C to 100°C it is formed into pellets by rotating a steel die that is perforated with pencil sized holes against inner pressure rollers to force the biomass feedstock into the holes at 70,000 kPa(10,000 psi) pressure extruded through the die and chopped or broken off at the desired length (1 cm±) on the outside of the die. The pellet fuel emerges at about 150°C and is subsequently cooled. The process takes up about 3% - 7% of the fuel's energy to supply the heat and horsepower for pelletizing.

STEAM GENERATOR SELECTION

The kind of energy desired influences the selection of the type of steam generator. The kinds of energy produced and discussed are heat, electrical and mechanical forms.

Process Heat

If a small amount of steam is desired to provide heat for coils in a typical heating or drying process (process heat) then a fire tube boiler would be appropriate for steam production in the range of 1,000 to 10,000 kg/hr at saturated steam temperatures and pressures to an upper limit of 2000 kPa . There is little advantage to superheating steam for typical heat applications because, at the very minimum, 2/3 of the heat is the latent heat available from condensing the steam. In larger process steam applications water tube boilers with natural circulation come into play. Water tube boilers become more appropriate at steaming rates of about 7000 kg/hr and up to about 300,000 kg/hr. The upper size limitation is dictated by water cooled grate design aspects. Actually there is no lower limit for water tube boilers. Buildings are often heated by small water tube boilers.

Heating for chemical processing applications is an entirely different subject and may require superheated steam or fluids other than water.

Electricity Production

If the form of energy desired is electricity then superheated steam is usually indicated. Since stresses in shells and plates found in the fire tube boiler rapidly increase with both internal pressure and size of boiler, steel becomes an inappropriate metal for construction. Since steel is the most economical high strength metal of construction, cost dictates that fire tube boilers can only be competitive in the small, less than I MW electrical power plants.

Most water tube boilers producing steam for electrical power generation will be designed for temperatures and pressures of superheated steam that are dictated by the turbine manufacturer. In water tube design departure from carbon steel to alloy steels occurs at about 400°C and alloys are changed in increments as steam conditions increase.

Some of the preferred steam conditions for power generation are shown in Table 10.

Table 10

PREFERRED STEAM CONDITIONS

ELECTRICAL GENERATION	STEAM PRESSURE	STEAM TEMPERATURE	FEED WATER TEMPERATURE
0.0 - 12.6 MW	4,100 kPa(600 psig)	440°C(825°F)	175°C(350°F)
12.7 - 44. MW	5,900 kPa(850 psig	480°C(900°F)	175 - 210°C
44 - 100 MW	8,600 kPa(1250 psig)	510°C(950°F)	210°C(405°F)
100 - 150 MW	10,000 kPa(1450 psig)	540°C(1000°F)	225°C(440°F)

These are very general and indicate turbine conditions and cost plateaus commonly used in the U.S. in the past.

These conditions may no longer be economical and smaller plants would, therefore, select higher steam conditions to take advantage of better heat utilization efficiency of the "higher pressure" boilers.

Cogeneration

Cogeneration produces both process steam and electrical power, in such cases, the steam conditions are similar to those needed for electrical power production. The steam turbines that drive the generators usually are of the extraction type (condensing). The steam condition of the steam generator must match the inlet steam conditions of the turbine. At some point(s) through the turbine, steam is often extracted for power cycle or process heat needs. The amount of extracted steam reduces the electrical output of the generator, because the steam has been removed before it has completed its work in passing completely through the turbine. The decrease in electrical power output in KW for each 1000 lbs of steam entering the turbine is shown in Figure 4-4. Exhausting steam to air extracted from a full-condensing turbine will reduce the electric power output of the generator from that steam by more than 50%. Cogeneration is generally less attractive to a utility producing electricity than to an industry using steam.

Cooling Systems

Cooling systems are required where condensing turbines are used. These systems provide water to cool the condenser, thereby reducing the pressure and temperature of the steam from the turbine to pressures below atmospheric and temperatures less than the boiling point of water. The greater the vacuum produced during cooling, the more shaft-power the turbine will deliver to the generator for making electricity. Figure 4-5 shows a typical flow diagram for a steam turbine with one extraction port for heating boiler feed water.

The water used to cool the condensor may come from a clean stream, lake or salt water body or a cooling tower. Using natural water bodies will work well if there is ample water and the temperature of the receiving water is not appreciably increased by the heat rejected from the condensor. The use of captive water bodies (cooling ponds) also works well, but their size is often quite large. The use of cooling towers is limited to the wet-dry

Figure 4-14

COGENERATION APPLICATIONS
POWER GENERATION VERSUS BACK PRESSURE

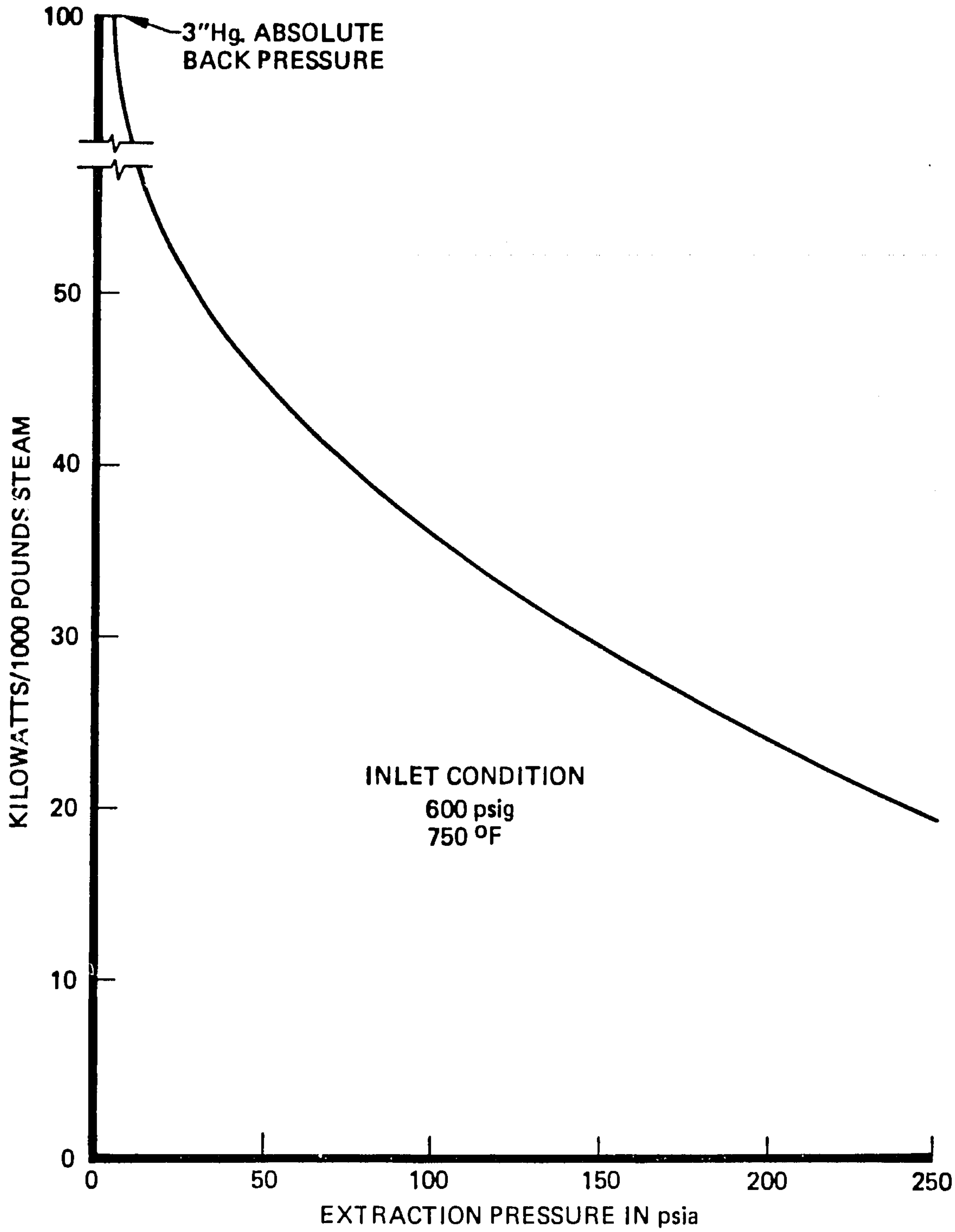


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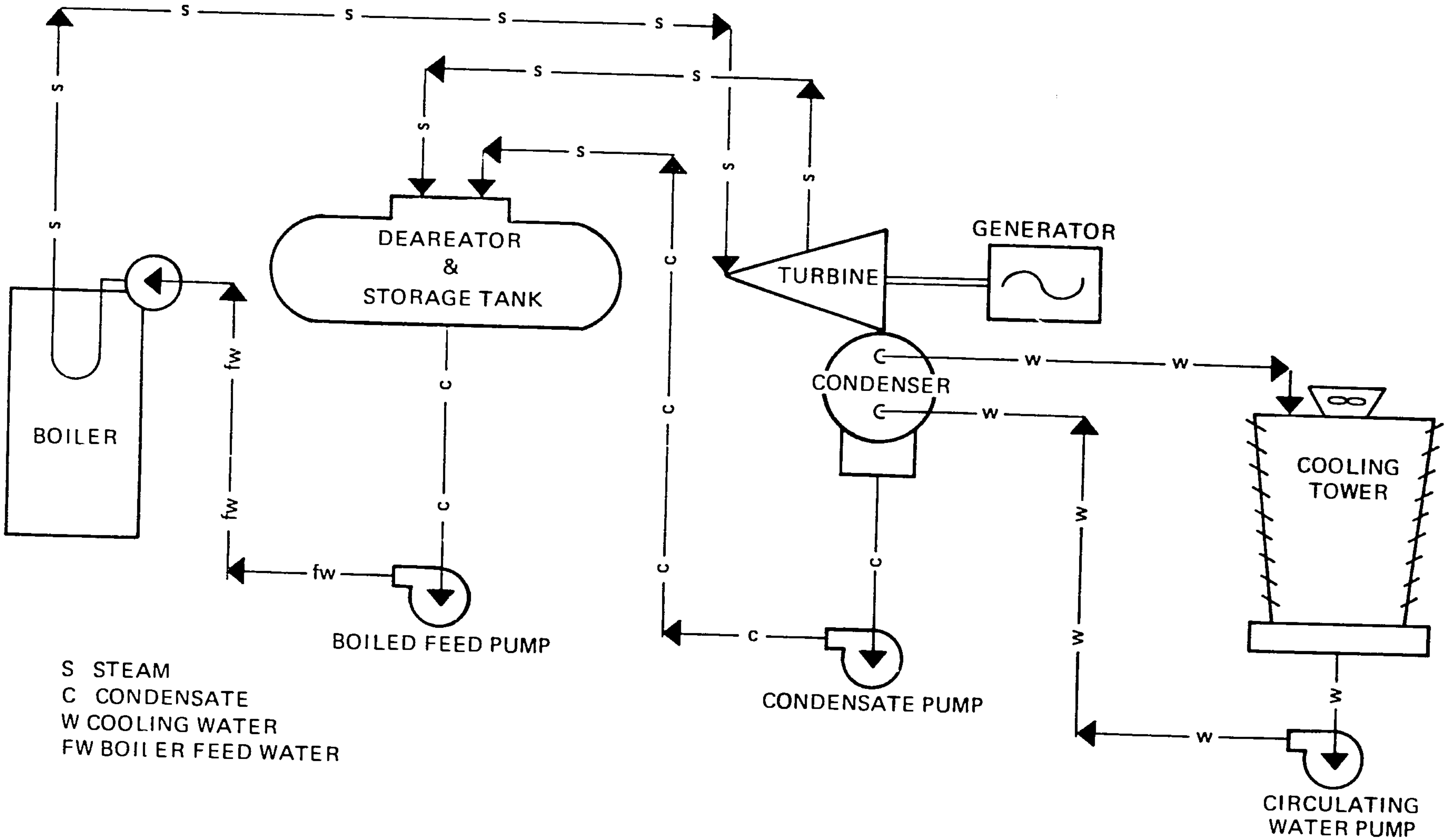
Figure 4-5

TYPICAL FLOW DIAGRAM OF A STEAM TURBINE WITH ONE EXTRACTION PORT



types for arid regions (where water must be conserved) to the mechanical forced draft types where there is ample water to evaporate for chilling the remainder of the cooling water.

Integrated Electrical Power Systems

The steam generator, turbine generator and cooling system must fit together in an integrated electrical power generation system. Boiler feed water is added to the steam generator when the steam or condensate is lost as the boiler blow down, as gland leakage in the feedwater pumps, as steam from traps and leaks in the system. The power cycle efficiency under any of the preferred steam conditions previously shown in Table 10 is generally enhanced by an optimum of 4 to 5 incremental condensate return or feedwater heating applications. The temperature of the condensate leaving the condenser is about 3 to 5°C above that of the cooling water leaving the condenser. Since most condensers operate at absolute pressures of 7 to 10 kPa(2 to 3 in. Hg) the temperature of the fresh condensate is about 42°C to 52°C. Feedwater is made of the condensate and is generally heated to the temperatures shown in Table 10. The energy necessary to heat the feed water is usually supplied from the extraction ports of the turbine and, therefore, the turbine is designed for supplying the steam to be used in the reheating of the boiler feedwater.

Mechanical Power

Steam is used for the energy source for mechanical prime movers. Applications such as pumping water to propelling steam locomotives are examples. Generally, prime movers are either reciprocating steam engines or mechanical drive turbines.

The steam engine has a place in the modern world. Whenever a need for a high torque, relatively low speed machine exists, the steam engine should be considered. The rugged dependability, long life, ease of maintenance, simplicity of operation are attributes. They are, however, in comparison to other devices, inefficient.

Throttle steam may vary from a few pounds pressure up to 10,000 kPa. Inlet steam temperature is limited to about 400°C due to the materials of construction generally employed. The quality of the initial steam may vary from dry, superheated, to saturated at approximately 40% moisture. The engine may exhaust to a back pressure for further use, to atmosphere or to a vacuum.

The foundation for a steam engine will be more massive than that of a turbine of equal horsepower because of the reciprocating motion.

The use of the versatile steam turbine to drive mechanical equipment, such as, fans, pumps, compressors, etc. is common. Their variable speed capability vs the constant speed of the steam engine is a most useful characteristic in some cases. The "off-the-shelf" mechanical drive turbine can vary in size from one horsepower to five hundred or more and the special sizes may range upward to several thousand horsepower.

Mechanical drive turbines may be manufactured for a wide range of inlet steam conditions. A steam quality limit is generally placed upon the machine by the designer-manufacturer. The excessive moisture is undesirable because of blade erosion. The turbine may exhaust at a back pressure needed for a subsequent process or to a condenser.

To take advantage of the turbine's higher efficiencies, associated with the higher RPM, the power is often transferred through a speed reducer to the driven equipment. Steam turbine drives are often used for standby or emergency drives in case of electrical power failure.

While not a purely mechanical application, steam is often used to create a vacuum by the use of an ejector. The steam-jet-ejector is a device designed to convert the pressure energy of the steam to velocity energy. By admitting a controlled air flow into a vacuum created by a high velocity, the air stream can be used to transport dry, fine particles of material, fly ash, sawdust, grain, etc. The steam ejector may also be used to help maintain a vacuum on a surface condenser, while simultaneously removing the noncondensible gases. The steam jets may also be useful in priming large pumps.

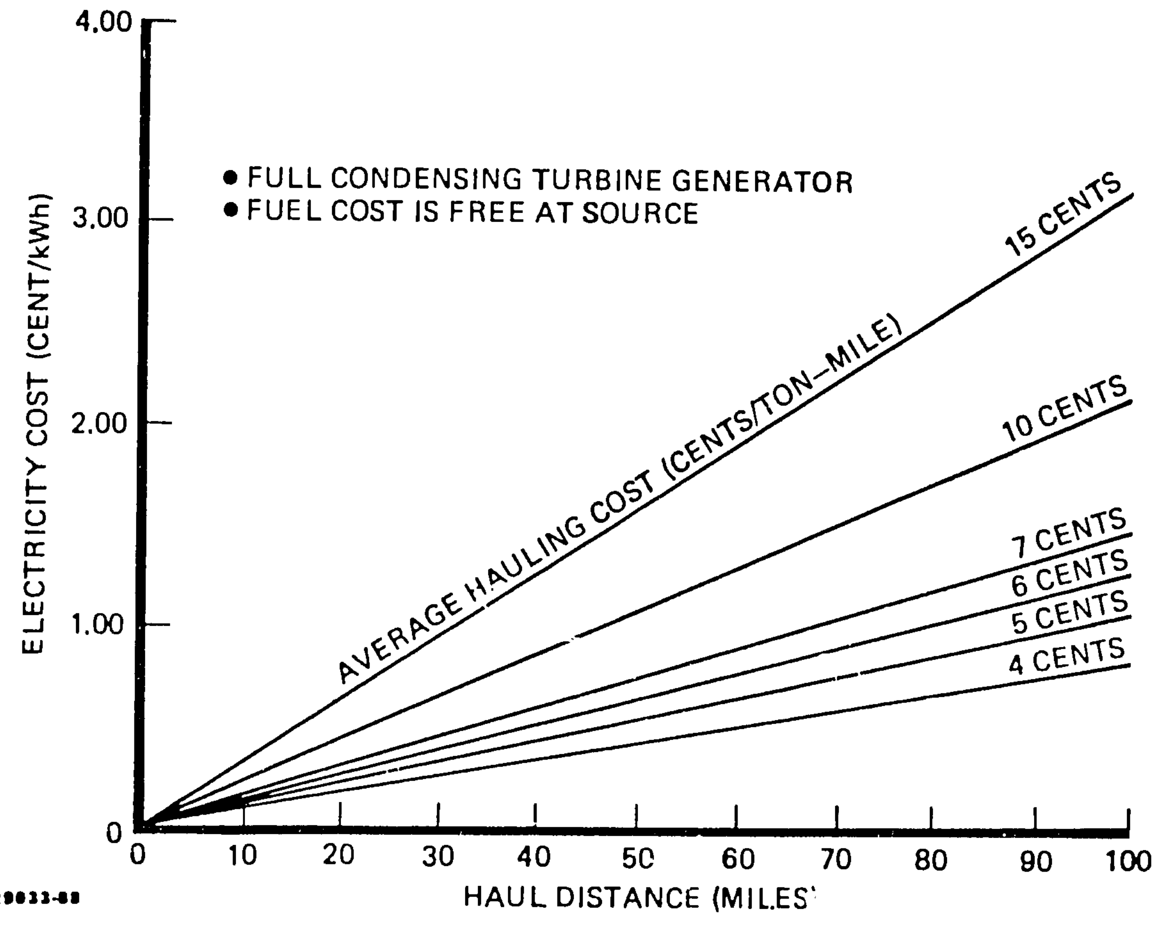
ECONOMICS OF BIOMASS COMBUSTION

Wood fired power plants generally do not exceed 50 MW in capacity at the industrial generating facilities in the USA. Most power plants generate between 5-20 MW of electrical power. Those smaller than 5 MW usually have some extenuating economic circumstances that makes the application practical, such as free fuel at the site. The larger plants over 20 MW have an advantage of lower capital and operating costs, but generally fuels are gleaned and hauled at considerable expense from many sources up to a radius of 80 to 120 km from the power plant. An economic haul distance is a significant expense that must be carefully estimated.

An example of the effect of hauling distance on the selling price of fuel may be seen in Figure 5-1:

Figure 5-1

EFFECT OF FUEL HAULING DISTANCE ON COST OF ELECTRICITY



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This example is for a mill residue fuel where the transportation would occur largely over paved roads. The type of truck, turning radii, characteristics of the roadbed, downhill vs uphill, tolls, roadblocks, weighing stations, delays and many other considerations influence hauling costs.

In rainy or snowy areas, covered fuel sheds become an economic advantage because the efficiency of combustion can be kept high with little energy lost to vaporizing the moisture when burning wet fuel. Figure 2-2 shows an example of how high moisture reduces the combustion efficiency in a wood fuel fired, grate-burning steam generator application. It, therefore, becomes prudent to keep the fuel as dry as possible.

Where wood residues are handled in volumes pacing the logging patterns of the area, fuel pile size might be .2 hectares/1 MW in areal size. If, however, the fuel supply were an agricultural biomass fuel that arrived during only one period of the year, produced by one growing season, we would expect to need possibly 1 hectare/MW just to store the fuel in piles about 10-12 meters high based on a light bulk density of approximately 100 kg/m^3 on an as-received basis. So fuel storage pile size depends on the frequency of replenishment and the bulk density of the material.

If storage piles are exposed to rainfall in areas where annual rainfall exceeds annual evaporation, it is quite likely that the fuels will not burn without costly predrying. When sawdust piles have been exposed to the elements for a number of years, the moisture content often exceeds 65% of the fuel weight and flame out occurs when the material is fed as a fuel to a boiler.

Biomass applications may involve the pelletizing of fuels which greatly reduces transport volume. Pelletized fuels are heavy and can only be transported on major roadbeds. The problem with transporting biomass fuels for long distances is that diesel oil or gasoline is needed to transport the fuel between two locations with one leg of the trip using an empty truck. Transportation costs often equal the preprocessing costs for burning wood residues.

SECONDARY ECONOMIC EFFECTS

Several natural resources are called upon to support a biomass burning power plant. Water, land and air resources are adversely impacted. These effects are usually not reflected in the economic evaluation of a power plant, but are mentioned here for reference.

Water is used in the steam generator, cooling tower, air pollution control system, boiler feedwater backwash and regenerating cycles, etc. The cost of the water is usually included in the Operating Costs, but the loss to the area from taking this water is not.

The spent water contains regenerant materials such as dilute sulfuric acid, caustics, and phosphates. The waste water is of no beneficial agricultural use and generally untouched by biological treatment methods now used. These wastes will degrade any receiving fresh water (to some extent) and can only safely be disposed to brackish water.

Soil nutrients that normally were returned to the soil as plant fiber, if hauled away and burned can only be returned to the soil if all the combustion products are distributed over the producing land. The nitrogen, potassium and phosphates fertilizing constituents are eliminated by air pollution and combustion control practices because they offend our senses. Yet the combustion processes have the ability to fix large amounts of nitrogen and generally return the caustic components in ash to the soil. The present situation results in a gradual degredation of the land unless fertilizers and essential nutrients are used to replace these losses.

Land becomes a capital cost and part of the power plant when it is acquired to provide the site for the power plant and fuel storage yard. The land taken out of service from some other use is land that was formally productive, even though the power plant may be a better use.

POWER PLANT COSTS

The costs of the power plant are commonly subdivided into the following categories:

- o Capital Costs
- o Fixed Operating Costs (annual)
- o Variable Operating Costs (annual)

Capital Costs

Capital costs can be divided into those representing the plant investment and those concerned with preproduction; such as, royalty allowances, interest during construction, inventory capital and land costs.

The Plant Investment costs include:

Construction Cost of the Plant
Offsite Facilities Costs
Engineering and Administrative Fees
Project Contingency
Sales or Use Taxes

The Construction Costs of the power plant are divided between those of the fuel preparation and handling ("front end" systems), the boiler plant, the power house, the cooling system and site improvements.

Fuel Preparation systems are described in Chapter 2, Principles of Combustion and Combustion Requirements under the section Front End Systems. These systems support the boiler and are not generally related to the power house or cooling systems.

The Boiler Plant construction comprises the foundations and boiler building, the steam generator and furnace, the valves and piping, the insulation of the boiler and piping, the feedwater and condensate systems, the air fans and ductwork, the electrical work, the instrumentation and controls, and the "back-end systems". Back-end systems generally include the primary and secondary air pollution controls, the induced draft fan and waste water disposal system.

The Power House construction comprises foundations and building; the turbine-generator with condenser; the valves, pumps and piping; the overhead crane; instrumentation and controls; the electrical panels and electrical work; the main switchgear and tie-in and the auxiliary oil, air, and liquid systems supporting the turbine generator.

The Cooling System construction may be as simple as a fresh water intake, irrigation pump and waste water outfall and diffusor, or it can be rather sophisticated with a mechanical draft wet and dry cooling system with foundations, towers, high volume pumps, cooling water softening and treatment, and waste water disposal system. Gravity cooling towers are generally too expensive for the less than 50 MW installations and for this reason they are not used.

Site costs include the grading, drainage, fencing, landscaping, utility piping, roads and parking.

Off-site costs are those beyond the property boundary of the power plant. These include the lines of utilities, transportation access and other factors. Good selection of a site often eliminates these costs entirely.

Rather than examining in detail all the Plant Investment costs and how they are arranged in the final analysis please refer to Table II .(The power plant costs shown are for a forest-residue facility with 50% of the steam extracted for industrial use. This facility had a parasitic power demand of 13% of it's power output and a utilization factor of 67% , an interest rate of 8-1/4% and a project life of 15 years.

Please note that the individual costs of the major facilities are added to obtain the Construction Cost. To this cost the Engineering and Administrative costs are added. A Contingency based on many factors is added, in this case 15%. The sum of the Construction Cost, Engineering and Administrative Costs and the Contingency makes up the Project Cost. To the Project Costs, sales or use taxes are sometimes added. (In this instance there were none).

Table 11

ESTIMATED COST OF ELECTRICITY GENERATED BY A 16 MW FOREST RESIDUE FUELED POWER PLANT WITH 50% COGENERATION

Capital Costs	Total	Annualized
Woodyard and fuel handling	$ 4,141,000	$ 491,205
Boiler and boiler house	12,830,000	1,521,895
Turbine-generator and building	4,999,000	592,981
Cooling tower	330,000	39,145
Site improvements	669,000	79,357
Construction Cost Subtotal	$22,969,000	$2,724,583
Engineering design	1,332,000	158,002
Contingency	3,445,000	408,693
Project Cost (Plant Investment) Subtotal	$27,746,400	$3,291,278
Preproduction costs	785,000	93,117
Inventory capital	248,100	29,430
Initial chemicals	10,750	1,275
Land	250,000	29,655
Allowance for interest during construction	2,916,300	345,932
Total Capital Cost	$31,956,550	$3,790,686
Fixed Annual Operating Costs		
Operating labor		$ 712,300
Maintenance labor		230,100
Maintenance Materials		186,000
Administrative and support labor		282,700
Total		$1,411,000
Variable Annual Operating Costs		
Waste disposal		$ 36,400
Chemicals		86,000
Other consumables		99,000
Rolling stock fuel		300,000
Generation fuel		1,500,000
Total		$2,021,400
By-product Credit (Steam sales price of $3/1000 lb of steam)		(1,936,800)
Total Annual Cost		$5,286,386
Annual Electric Power Generation		81,700,000 kWh
Average Busbar Power Cost		64.7 mills /kWh

Operating and Maintenance

The operation and maintenance costs at the power plant are often divided into fixed and variable operating costs. The fixed costs include such things as operating labor, maintenance labor, maintenance materials and equipment, and administrative and support labor. These costs do not vary with the production of electrical power.

Fixed Costs. The Operating Labor is calculated as the sum of the labor costs from two distinct arenas of job function: the wood processing/fuel pile and the power plant (per se). The power plant operation in the example was estimated to require three labor positions for three shifts daily, every day of the year (8760 hrs/year); the wood processing and handling required five jobs for two shifts, only five days per week for every week of the year (4160 hrs/year). The Operating Labor Costs can be calculated as the product of the number of jobs times their labor rates times the number of hours worked per year.

In the example in Table II Maintenance Labor is derived from an estimated requirement for eight operating jobs for one shift daily, five shifts per week. The estimated amount for Maintenance Materials uses the factor employed elsewhere in the electrical utility field of 1.5% of the capital cost per year.

Administrative and Support Labor is calculated at 30% of the sum of the Operating and Maintenance Labor in the example. This represents the overhead labor portion and management portion of the activity.

By adding the Operating Labor, Maintenance Labor, Maintenance Materials and Administrative and Support Labor, the Total Fixed Operating Costs were estimated.

Variable Operating Costs are comprised of the categories of water, waste disposal, chemicals, other consumables and fuel. No variable maintenance costs were included in the example.

The water needs may be supplied from rivers and/or wells and when this is true there is no rate charge assigned. The water pumping and treatment costs are simply included in the parasitic in-plant power consumption, an amount subtracted from gross power to yield net salable power.

The cost of the chemicals for the demineralizer, boiler additives and other plant uses must be added. These can be obtained from chemists working in this field.

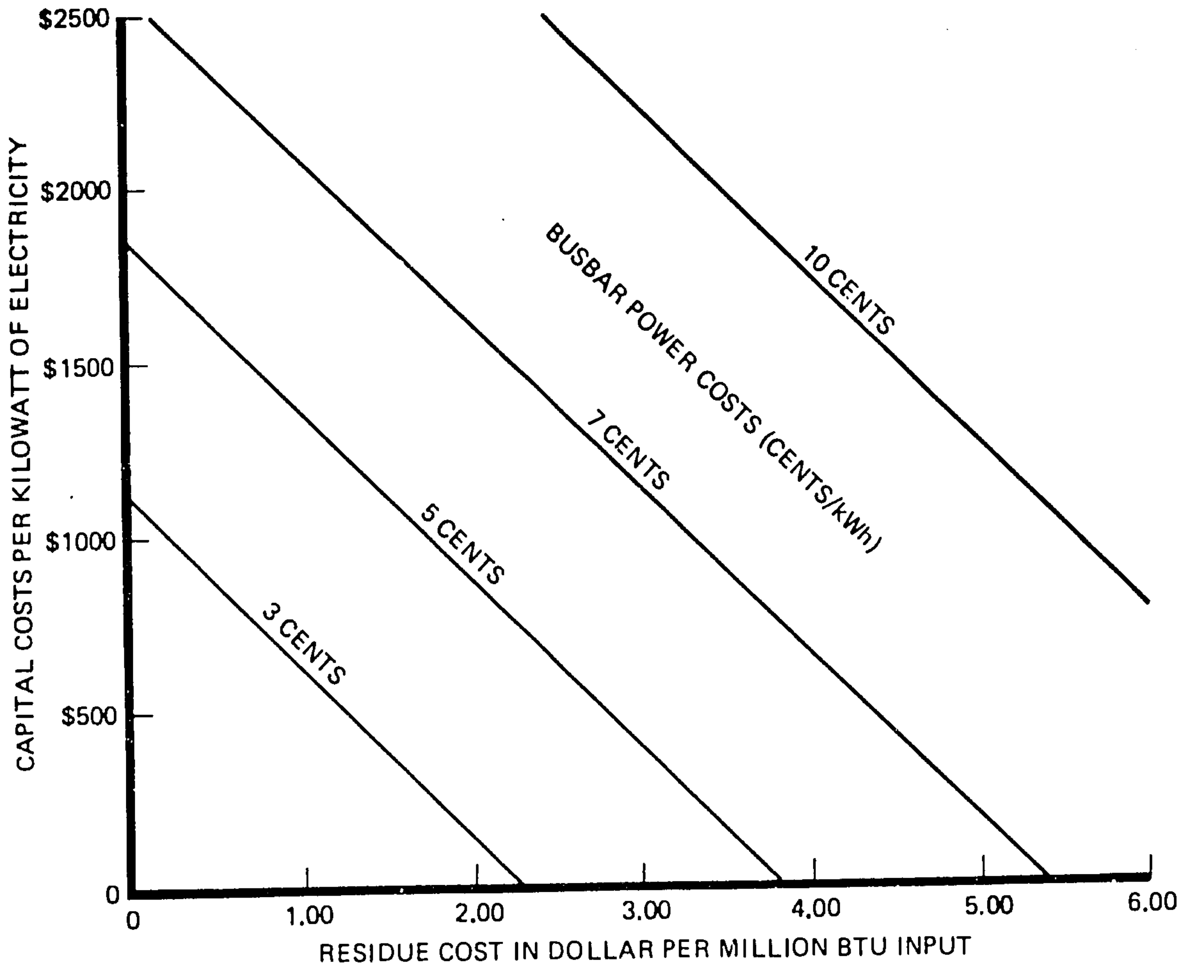
Other consumables include both General Other Consumables and Rolling Stock Fuel. These can be anything from paper towels to engine lubricants and fuels.

The cost for Waste Disposal may be estimated on the basis of the number of cubic yards per year of wet or dry ash hauled based on the cost of operating the truck and the number of trips to the disposal site that it must make annually.

The last and by far the most significant variable operating cost is the cost of the biomass fuel itself. The acquisition costs of biomass fuel may include the retrieval, collecting, preprocessing, loading, transporting, offloading, sizing, grinding, conveying, storage, reconveying and feeding costs. These costs include labor, equipment depreciation or rental, electrical power, fossil fuel, maintenance and repair costs. If the ground and ready to be fired material were delivered to the power plant each day for firing, the sellers cost at this point (with some exceptions) would represent the fuel acquisition costs; however, in most applications the fuel must be obtained from some one else.

To demonstrate the importance of fuel costs on busbar power costs for a typical full-condensing, forest-residue-fired, electric generating plant, figure 5-2 was prepared. The situation graphed shows the effect of biomass cost on the final busbar power cost. Also shown are typical costs for fuels as fired. Where the fuel comes from and how it has been handled and stored makes a difference in how much heat can be obtained from burning the fuel.

BREAK EVEN COSTS*
24 MW BIOMASS FUELED POWER PLANT



ESTIMATED JANUARY 1981 FUEL COSTS IN $1/MILLION BTU INPUT

FUEL		$/MM BTU
OIL	(NO. 5 OR 6)	6.05
GAS	(NATURAL)	2.50
COAL	(LOW SULFUR)	1.65
WOOD	(FOREST RESIDUE)	2.20
	(MILL RESIDUE)	1.10

*20 YEAR LIFE, 8% INTEREST, 0% INFLATION

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The sum of the water, waste water and ash disposal, chemicals, other consumables and biomass and auxiliary fuels make up the Variable Operating Costs.

By-product Credits are revenues primarily from the sale of steam, but additional revenue can come from any other material sales such as hot water, distilled water, char and fly ash.

Total Annual Cost

The total annual cost is the algebraic sum of all the other costs and credits. The Total Capital cost, plus the fixed Annual Operating Cost, plus the Variable Annual Operating Costs minus the By-product Credit equals the Total Annual Cost. The Total Annual Cost when divided by the actual amount of power sold in a year gives the Average Busbar Power Cost.

Please note that the 16 MW electrical power generating plant used 13% of its electrical power in-plant for the pumps, fans, preprocessing equipment, lighting, heating, etc. The plant was assumed to operate 9 months per year, but at only 89.27 percent of its design capacity. The resulting annual power production was:

16,000 kWh(8766.24 hr/yr)(1-.13)(9/12).8927 = 81,700,000 kWh

The Average Busbar Power Cost was:

$5,286,386/yr ÷ 81,700,000 kWh/yr = $.0647/kWh.

The plant operated at only 58-1/4% of its design capacity. A plant should not be expected to operate at over 70% of its actual capacity simply because this is what normally happens in a power plant and there is a great tendency to overestimate the revenue that they will produce.

Other Method of Economic Presentation

Escalation of costs and revenues were not mentioned previously because, generally, the concept is beyond explanation by simple engineering economics. If the capital portion of the project is to be financed with borrowed money, then interest payments and escalation occurs throughout the capital recovery period. The capital recovery period might be as low as 2-1/2 years for an industry to possibly 30 years for an electrical utility. The capital cost, future revenues, operating and maintenance costs, and even fuel acquisition costs may be escalated at predetermined rates based on the judgment of the economist over a period of years in the future. Some utilities use either a discounted-cash flow method of determining their financing or a cost levelization method. In the former method all costs are escalated at different fixed rates, but interest remains at a fixed rate.

Individual costs are escalated and determined annually throughout the capital recovery period when using the discounted cash flow method. Each year of the capital recovery period is displayed to show the varying arrays of costs as influenced by interest, inflation, repair frequency, etc.

In the levelization method, the escalation and interest occur at certain fixed rates and a present day cost is increased about the same as

$$\frac{P \sum_{x=1}^{n} \left(1 + \frac{i - e}{100}\right)^{x} \quad x = 1, 2, 3 \ldots n}{n}$$

in which P is the present value, e is the escalation rate in percent annually, i is the annual interest rate and n is the period of capital recovery in years. By using the levelization technique, the impact of escalation and interest can be brought back to a present worth as a multiplier to the cost, and therefore, shown as one value.

Hazards to Investment in Biomass Power Plants

There are some distinct disadvantages to building biomass fuel power plants that are not associated with fossil fuel plants. General labor unrest can influence either power plant except biomass plants probably involve more labor activities than do other fuels.

The agricultural businesses, the wood products industry and any competing industry desiring the crop or the crop residues can upset the economics of fuel acquisition. The crop or residue will be sold to whomever pays the most money. Thereafter the price for the biomass may be too expensive to use for electrical energy production.

Biomass sources such as farms, fields and forests are subject to natural disasters of fire, pestilence, floods, drought, dust storms, etc. that may destroy or reduce the fuel supply. Fossil fuel sources, on the other hand, are not influenced by the botanical aspects of the disasters.

A small power plant can use up much of the electrical production capability in the motors that drive the pumps, fans, and especially the air pollution control equipment. In-plant power consumption must be carefully determined. When selecting motors and turbines one should avoid a selection in which there is very little difference in energy consumption when the prime mover is at full load or half load.

SUMMARY AND COMMENTS

Countries which have natural resources that produce residues in the biomass area have energy which can be converted into useful energy. These countries should examine the potential for reducing the import of petroleum or other similar expensive import types of energy by better utilization of these biomass resources. One of the cheapest and easiest methods of conversion to another form of energy is a direct combustion system to convert the biomass into either steam or a combination of steam and electric energy. The conversion into electric energy makes the energy easily transportable to the point where it can do the most good for substitution or new development in residential or industrial areas.

The direct combustion of biomass should be carefully evaluated before its conversion should be carefully evaluated before its conversion is undertaken. The evaluation should not only include the economics of making this change but the location of the unit in relation to environmental concerns as well as the source of biomass and the utilization of the converted energy. Heavily forest-type growth area obviously present the best opportunity to obtain biomass for fuel. Of the various biomass sources that are available to a country wood appears to be the one that has the greatest density and the greatest heating value from a volumetric basis. In many cases the utilization of forest in tropical areas can produce a side benefit of allowing a better species of tree to grow where the least desirable ones are removed for fuel. This of course would be a fringe benefit which can in some countries create a whole new industry by allowing the growth of specific commercial grade species of trees.

A careful analysis of the type of fuel to be burned and its burning characteristics is essential to the application of a proper burning apparatus or device. The density of the biomass is particularly important to the firing mechanism that will be employed and should not be overlooked in the selection of the proper equipment. The same is true in the selection of the boiler to produce steam. The method of converting the steam into useful energy is rather common place and generally understood by engineers in most all countries. Since the turbine generator for electric generation operation is only dependent on steam quantity and quality and not the source of the fuel, the electric generation system is basically a conventional system which has been employed in most all countries.

Fuel preparation is extremely important as to the type of burning system that is to be used. The preparation of this fuel is dependent on the moisture content, the size of the material, the density of the material and the type of burning system (suspension or grate burning) which will be employed.

The environmental aspects cannot be overlooked in regards to the burning and combustion of biomass. All biomass burning in combustion systems produce considerable amount of particulate in the flue gas stream from the products of combustion. These particulates must be removed properly to keep our environment in its original state. A careful analysis of the type of environmental control system which is applied to the biomass burner can effectively control environmental impacts. In addition to environmental concerns for air pollution, we must not overlook the fact that considerable amount of ash and debris, which is potentially a contaminant to the ground environment, is the left over residue from the products of combustion in the form of ash, cinders and dust. These materials must be disposed of and generally they are placed in a landfill. However, caution must be used if they are used as a landfill that they do not contaminate any present streams or water table which may be in the area.

Proper water is important to the making of steam in any type of boiler, and especially in the case of a boiler which is going to be used to produce electric energy. Therefore, caution should be used in the feedwater control systems to make sure that the steam which is generated for the use in the turbine is of a quality which will not cause considerable maintenance and high erosion in the turbine blades.

A reminder that the selection of the burning system is greatly dependent on the results that are intended to be achieved and since we have four types of burning systems which have been considered, each should be evaluated in conjunction with the degree of burning, the type of burning and the location of the facility with the intended use of energy from biomass to a more useful form.

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In West Germany about 4 million tons of straw and about 14 million tons of wood are available annually, for which there is not an important economic use. This corresponds to an energy potential of 10 million tons of coal equivalent, or 6.86 million tons of heating oil. This heat content could be used for heating and drying operations. For this purpose special heating installations are needed. Some installations are already on the market, while others are being developed. A two phase burning process is necessary in order to achieve a high efficiency while still staying within admissible emission levels. An economic use of wood and straw for process heat in agricultural applications exists at the current price levels.

LARGE BARK AND WOOD WASTE FIRED BOILER: A CASE HISTORY. Nanney, W.M.; Gustafson, F.C. (Weyerhaeuser Co., Longview, Wa). pp 19-25 of TAPPI conference papers: 1976 engineering. Book I. Atlanta; Technical Association of the Pulp and Paper Industry (1976).

From TAPPI engineering conference; Houston, TX, USA (4 Oct. 1976).

The development of the project from conception through startup is presented. The approach used to define the objectives, evaluate alternatives, select equipment, and implement the final decision is discussed. The major areas included in the discussion are receiving, storing, and preparing wet and dry wood waste for controlled combustion in a high pressure steam generator; flue gas cleaning, ash disposal, feed water treatment, and electric and steam ties to existing mills.

DRYING AND NON-SLAGGING SUSPENSION BURNING OF HIGH MOISTURE AND HIGH ASH WOOD RESIDUE. Livingston, A.D. (Guaranty Performance Co., Inc., Independence, KS). PP 63-71 of Energy and the wood products industry. Madison, WI; Forest Products Research Society (1976).

From Forest Product Research Society conference; Atlanta, GA., USA (Nov. 1976).

Steps in the drying of high moisture wood residue for fuel in a rotary drum dryer is discussed. Are outlined. Development and performance of a burner for the non-slagging suspension burning of high ash dry wood are discussed. Advantages, as well as capital and operating costs, of the drying and suspension burning of wood residues are pointed out. (JGB)

WOOD-COMBUSTION SYSTEMS. Bloomfield, R.G. pp 89-103 of wood chips for fuel and energy. Albany, NY; legislative Commission on Energy Systems (1978).

From Conference on wood chips for fuel and energy; Potsdam, NY, USA (11 January 1978).

Several systems for burning wood residues are described: the dutch oven with pile burning; thin-bed systems on stationary grates; traveling grates; water-cooled grates; refractory-hearth burning; suspension burning; combinations of suspension and burning on different types of grates or hearths; gas-pyrolysis; and fluidized-bed combustion. The choice of a system depends on the physical properties and availability of the residue to be burned and the moisture content of the fuel. The total combustion system must be taken into consideration as well as the firing system. The operation and relative advantages of various systems are described in terms of these factors as they apply in the Northeast.

IN-HOUSE GENERATION OF ELECTRICITY FROM WOOD WASTE RESIDUE. Morton, FL. (Abitibi Paper Co., Mississauga, Ont.). pp B199-B203 of 63rd annual meeting of the Technical Section, C.P.P.A. Preprints. Montreal: Canadian Pulp and Paper Association (3977).

From 63. meeting of the Technical Section, C.P.P.A.; Montreal, Canada (1 Feb. 1977).

The potential for use of wood waste in producing electrical energy for in-plant use is dependent upon a number of factors including availability of wood waste, efficiency in preparing it for use as a fuel, and the cost of other fuels at the plant site. These factors are considered in examining the possibility of in-house generation of electricity at two plants.

CONVERTING WOOD RESIDUES TO PROFIT. Sowards, N.K. Idaho Falls, ID; Energy Products of Idaho (1976). 38 p.

The economics of wood residue firing for industrial boilers using proven combustion processes, applications of energy conversion within the wood products industry, and the economics of converting a typical gas- or oil-fired steam generation system to wood waste firing are discussed. It is stated that the key economic factors in making wood-fired systems pay are: properly sized systems; near capacity operation; maximum automation; maximum on-stream time, and as large a capacity as feasible. It is concluded that if wood residues in quantity are available conversion of gas- or oil-fired equipment to wood residue-firing should be economically attractive. (LCL)

STUDY OF COMBINED PULVERIZED COAL AND BARK FIRING IN INDUSTRIAL BOILERS. Marks, W.R.; Witkowski, S.J. (Babcock and Wilcox Co. North Canton, OH). pp. 181-189 of TAPPI conference papers: 1976 engineering. Book I. Atlanta; Technical Association of the Pulp and Paper Industry (1976).

From TAPPI engineering conference; Houston, TX, USA (4 Oct. 1976).

The design of pulverized coal and bark boilers and their evolution from the last fifteen years to the present is studied. Consideration is given to the impact of fuel availability and to the impact of the Environmental Protection Agency regulations on unit design. Also discussed are factors involved when future and other fossil fuels are included. One pitfall to be avoided when designing for future capability is that of overdesign. To design a boiler for an extreme condition which may never be realized is both costly for the buyer and often difficult for the designer.

BOILER HARDWARE FOR BURNING WOOD WASTE. Fuller, F.E. (Fuller Engineering Associates, Birmingham, Al). pp 80-85 of Energy and the wood products industry. Madison, WI; Forest Products Research Society (1976).

From Forest Product Research Society conference; Atlanta, GA, USA (Nov. 1976).

Success in burning wood waste can be achieved by proper application of fuel preparation, fuel feed system, furnace and boiler equipment, and dust collector equipment. Wood waste is classified into three categories: dry waste, bark, and unclassified. Depending upon the quantity and characteristics of the wood waste, grates (stationary or moving) or burners (cyclone or suspension) may be applied. Various design parameters are considered such as heat release rates, air temperature, and location of auxiliary burners. Consideration is given to furnace height, wall construction, boiler tube bank arrangement, and auxiliary equipment as related to operation, maintenance, and cost. Capital costs vary widely for a given installation. Without proper application, numerous problems are encountered in burning the wood waste.

COMBUSTION CONTROL WOODWASTE FIRED BOILERS. Wolf, J. (McBurney Corp., Atlanta, GA). pp 86-92 of Energy and the wood products industry. Madison, WI; Forest Products Research Society (1976).

From Forest Product Research Society conference; Atlanta, GA, USA (Nov. 1976).

Various techniques used in combustion control systems to monitor energy balance, steam demand requirements, and energy input (fuel) to a boiler furnace are discussed. Combustion control systems must be arranged to control fuel input to a boiler furnace in the correct relationship to combustion air requirements so as to maintain safe conditions over the operating range of the boiler. Combustion control systems must also be designed to interface with other furnace sub-systems such as flame monitoring and furnace purge systems. Selection of hardware that monitors process variables such as pressures, temperatures and flows, and converts these measurements into actuating signals to manipulate final operators which regulate fuel and air, is of great importance beyond personal preference. Some hardware designs are limited to simple control systems and, therefore, have limitations when processes require considerable sophistication. Generally speaking, as boiler furnace refinements are applied, such as demands for higher combustion efficiencies and lower stack emissions, hardware of greater flexibility must be used.

FLUIDIZED BED COMBUSTION SYSTEMS FOR THE WOOD PRODUCTS INDUSTRY. Sowards, N.K. pp 9;, Paper 3 of Recovery of energy from combustible wastes, primarily from forest products. Coeur d'Alene, ID; Energy Products of Idaho (1979).

Development work on a fluidized bed combustion system is followed to explore the potential for utilizing wood wastes to generate power at a centralized location. The program originally only considered incineration processes, but was then redirected to include recovery of useful forms of energy from the incineration process. The basic Fluid Flame combustion process is described and some typical energy conversion applications are mentioned.

NEW PACKAGED BOILER UNIT BURNS FARM, WOOD WASTES. Energy User News; 3: No. 15, 11(10 April 1978).

Packaged boiler systems that burn wood or agricultural wastes to produce either steam or hot water have been marketed by the Ray Burner Co. of San Francisco since 1972. Prices for wood waste boilers range from $75,000 to $175,000, depending on the characteristics of the fuel and the storage requirements.

Additional equipment may be needed to process or pelletize the fuel. The Ray Burner Co. analyzes each customer's fuel system to determine the best combination of boiler and equipment to install. A higher heat release is available from the company's new dual-burning method that burns large particles on a grate and smaller particles in suspension. Unburned fuel is recycled to reduce fly ash and increase efficiency.

HOG-FUEL GENERATOR PARES OIL USE AT GEORGIA-PACIFIC. Dell, A. Energy User News; 2; No. 34, 9(29 Aug. 1977).

Hog fuel (paper mill waste products) has been used by the Georgia-Pacific Pulp and Paper Co. to generate power and eliminate the need for fossil fuels at both the sawmill and the paper mill. Boiler efficiency in the turbine generating system was enhanced by the addition of a superheater and two boiler feed pumps. Enough hog fuel is available for the 400 tons used to generate electricity and to generate steam for a lumber-drying kiln. Good wood wastes are used to make paper, while hog fuel consists of bark, wood chips, and sawdust. (DCK)

APPENDIX B

List of Manufacturers

American Air Filter Co., Inc.
American Fyr-Feeder Engineers
Ametek
Atlas Systems Corp.
Babcock and Wilcox
Belco Pollution Control Corp.
CEA-Carter International, Inc.
Coen Company, Inc.
Conterma-Constructora Industrial e Termo Tecnica S.A.
Croll-Reynolds Co., Inc.
Detroit Stoker Co.
FMC Corporation
The Foxboro Company
Gotaverken Energy Systems Ltd.
Gruendler Crusher & Pulverizer Co.
Guaranty Performance Co., Inc.
Hobbs International, Ltd.
Joy Industrial Equipment Co.
E. Keeler Co.
Kinergy Corporation
Louis Allis Division
Mardee Corporation
McConnell Industries
Morbark Industries, Inc.
Peabody, Gordon-Piatt, Inc.
Radar Companies, Inc.
Rettew Associates, Inc.
Rexnard
Riley Stoker Corporation
Schutte Pulverizer Co., Inc.
Tacuma Co. Ltd.
The Terry Steam Turbine Company
Weiss USA Information Center
Wheelabrator-Frye Inc.
Williams Crusher International, Inc.
Zurn Industries, Inc.
Zurn Industries, Inc. Energy Division

BOILERS

EQUIPMENT SUPPLIERS

BOILERS

BABCOCK & WILCOX
P. O. Box 351
20 South Van Buren Avenue
Barberton, Ohio 44203
(216) 753-4511
TLX 98-6406

Contact: G. A. Sanden, Administrator
International Marketing Agreements

Complete Range of Biomass Burners and Boiler Sizes.

Foreign Sales Offices

Josueth Gonzales, Ltda.
Apartado 4870-CCI
Quinto, Ecuador

Middle East Trading &
Engineering Company
2, Sherif Pacha Street
(Lewa Building)
Cairo, Egypt

P. T. Fajar Mas Murni
P. O. Box 195/KBY
Jakarta, Selatan Indonesia

JISCO Co.
European Operations
35 Bridge Street
Hitchen
Hertfordshire SG5 2DG
United Kingdom

Aravah A.T. I., Ltd
P. O. Box 14051
Tel Aviv 67136, Israel

Sepro, S.R.L.
Via Turati, 26
20121 Milano, Italy

C. Itoh & Co., Ltd.
CPO Box 136
Takoyo, Japan

Modern Arab Construction
(U.K.) Ltd.
P. O. Box 2BN
London W1A 2BN, England

McDermott House
140 Wembley Park Drive
Wembley, Middlesex Ha98JD
England

9300 South Dadeland Blvd.
Dadeland Towers Suite 207
Miami, Florida 33156

Maxwell Road
P. O. Box 3034
Singapore 9050

P. Galimberti & Cia S.A.
Avenida La Plata 1522
Buenos Aires Argentina

Combrasma, S.A.
Caixa Postal No. 8225
Sao Paulo Brazil

Babcock & Wilcox (Chile)
Casilla 13510
Santiago Chile

Whashin Industrial Co., Inc.
C.P.O. Box 1121
Seoul, Korea

Al Nawasi Trading Company
P. O. Box 3204
Safat, Kuwait

Corporation Tecnica de Comercio S.A.
Casilla 1537
Lima, Peru

BABCOCK & WILCOX

Foreign Sales Offices
Continued

Engineering & Construction Corp of Asia
MCC P. O. Box 967
Makati, Metro Manila, Phillippines

Portilla Corporation
G.P.O. Box 4128
San Juan, Puerto Rico 00936

Modern Arab Contractors
P. O. Box 172
Al-Khobar, Saudi Arabia

Energesa
General Sanjurjo, 55
Madrid-3, Spain

Steam S.A.
Avenue de Jurigoz 10
CH-1006 Lausanne
Switzerland

Fortune Engineering & Trading Co., Ltd.
P. O. Box 22016
Taipei, Taiwan
Republic of China

Photi-Ratana Engineering
& Pharmaceutical Co., Ltd.
P. O. Box 11-1074
Bangkok, Thailand

Fenni-ama Ic Ve Dis Ticaret A.S.
Kizilay Emek Ishani Kat 18
Ankara, Turkey

The Marketing & Construction Co.
P. O. Box 750
Abu Dhabi, United Arab Emirates

Parker Associates
Intourist Hotel
No. 1 Gorky Street
Moscow, USSR

Babcock & Wilcox de Venezuela S.A.
Apartado 14211
Caracas 101, Venezuela

EQUIPMENT SUPPLIERS

BOILERS

COMPANHIA BRASILEIRA DE CALDEIRAS E EQUIPAMENTOS PESADOS

Praca Joao Mendes 42-18-19.0 Andar
Sao Paulo, Brazil

TLX 55-11-37-8591 Through 37-8595

Wood Fired Boilers

CONTERMA CONSTRUCTORA INDUSTRIAL E TERMOTECNICA S.A.

Rua Capote Valente, 1324 & 1344
ZP9 - Caixa Postal, 2519
Sao Paulo, Brazil

TLX 55-11-65-7101 & 65-7104

Wood Fired Boilers

ENERGY DIVISION
ZURN INDUSTRIES, INC.

1422 East Avenue
Erie, Pennsylvania 16503

(814) 452-6421
TLX 91-4473

Contact: Rebecca Stephens
International Marketing Associate

Foreign Sales Offices

Licensees: Argentina, Brazil, Canada, Denmark, India, Peru

Representatives: Australia, Costa Rica, Israel, Turkey, Taiwan, Philippines, Venezuela

Send all inquiries to the attention of Rebecca Stephens, Energy Division for appropriate referral.

BOILERS

ENERGY DIVISION
ZURN INDUSTRIES, INC.

1422 East Avenue
Erie, Pennsylvania 16503

Contact: Rebecca Stephens
International Marketing Associate

ZURN STEAM GENERATING SYSTEMS:

Design	Capacity Range	Description
Keystone® Watertube Steam Generators	6,000-600,000 pph	Factory-assembled or modularly field-erected for firing gas and/or oil and/or carbon monoxide (CO?) and other waste gases. Request brochure SB-71
"VL" Watertube Steam Generator	10,000-60,000 pph	Factory-assembled for firing coal wood or other solid wastes as well as combination/future solid, gas, oil. Request brochure SB-81
"VC" Watertube Steam Generators	50,000-150,000 pph	Field-erected, bottom-supported, cross-drum for firing coal, wood or other solid wastes as well as combination/future solid, gas, oil. Submit requirements (Brochure being revised)
Cross-Drum Watertube Steam Generators	100,000-1,000,000 pph	Field-erected, bottom or top supported, single or multiple pass. Able to be designed for firing most gaseous, liquid, or solid fuels as well as for waste heat or waste fuel energy recovery. Request brochure SB-74
Waste Heat Energy Recovery	20,000-1,000,000 pph	Available in a variety of two and three drum watertube designs including extended-surface, non-extended surface (baretube) and gas turbine exhaust. Custom firetube designs also available. Submit requirements (Brochures being revised)
Auxiliary Components	Any Capacity	Economizers Request brochure SB-80; Spreader Stokers Request brochure SB-62; Steam Purity Components Request Flyers SG-5, SG-6

ZURN a step ahead of tomorrow

ZURN INDUSTRIES, INC.

EQUIPMENT SUPPLIERS

BOILERS

GOTAVERKEN ENERGY SYSTEMS, LTD.

111 Railside Road, Suite 300
Don Mills (Toronto)
Ontario, Canada M3A 1B2
(416) 441-2421
TLX 06-966773

Contact: R. J. Curry
Vice-President and
General Manager

Wood Fired Boilers - Conventional Equipment - 3.2 to 50.4 kg/S (25,000 to 400,000 lbs/hr) Steam

Reference: Product and Contact Guide
List of Installations
Industrial Steam Boilers
Efficient Firing of Wet Bark and Wood Waste

List of Installations:

In Operation	Purchaser	Steam Flow Metric T/H (bark/comb)	Outlet Steam Pressure °C	MPa	Remarks
1959	Philippine Wallboard Corp., Nasipit Lumber Co, Philippines	14/14	425	2,7	S
1960	Nymölla AB, Nymölla, Sweden	4/18	450	6,1	S
1961	Wifstavarfs AB, Vivstavarv, Sweden	40/65	325	4,2	S
1961	Jönköpings Vestra Tändsticksfabrik, Jönköping, Sweden	12	300	2,3	P
1962	Skogsägarnas Industri AB, Mörrum, Sweden	30/50	450	5,8	S
1962	Oppboga AB, Fellingsbro, Sweden	2/12	375	3,9	S
1962	Svenska Cellulosa AB, Svartvik, Sweden	15/130	490	5,9	A
1962	Timmele Färgeri AB, Timmele, Sweden	12	Sat.	1,0	P
1963	Holmens Bruks- och Fabriks AB, Hallstavik, Sweden	20/40	360	3,8	S
1964	AB Electro-Invest, Stockholm, Sweden (Klabin, Monte Alegre, Brazil)	35/35	430	4,6	S
1965	Svenska Cellulosa AB, Obbola, Sulfitfabrik, Obbola, Sweden	29/54,5	450	5,9	A
1965	Billeruds AB, Gruvön, Sweden	40/100	480	6,0	S + A
1966	Svenska Cellulosa AB, Matfors-Ortvikens Pappersbruk, Sundsvall, Sweden	27/130	495	5,9	A
1967	Billeruds AB, Gruvön, Sweden	13/22	180	1,1	A
1969	Kopparfors AB, Hammarby Sulfitfabrik, Hammarby, Sweden	17/50	450	6,0	A
1970	Hylte Bruks AB, Hyltebruk, Sweden	40/100	450	6,4	A
1970	Billeruds AB, Säffle, Sweden	16/50	480	6,0	S
1970	Svenska Cellulosa AB, Timrå, Sweden	46,5/200	450	5,9	A
1970	Nymölla AB, Nymölla, Sweden	40/100	450	6,4	A
1971	Örebro Pappersbruks AB, Örebro, Sweden	4/12,5	Sat	1,6	P

BOILERS

GOTAVERKEN ENERGY SYSTEMS, LTD.

List of Installations:

In Operation	Purchaser	Steam Flow Metric T/H (bark/comb)	Outlet Steam Pressure °C	MPa	Remarks
1974	Bergvik och Ala AB, Sandarne, Sweden	10/50	425	3,6	S
1975	MoDo Cell AB, Husum, Sweden	80/80	450	6,5	S + R
1975	Kopparfors AB, Norrsundet, Sweden	26/55	450	6,0	S
1975	AB Scharins Söner, Clemensnäs, Sweden	20/30	Sat	3,2	S
1977	Uddeholms AB, Skoghall, Sweden	50/60	520	10,2	S + R
1978	Aracruz Celulose S.A., Brazil	92/170	480	6,4	S + R
1978	Holmens Bruk AB, Braviken, Norrköping, Sweden	40/70	475	6,0	S
1978	Holmens Bruk AB, Vargön, Sweden	25/30	375	3,2	S
1978	AB Iggesunds Bruk, Iggesund, Sweden	70/150	495	6,4	S + R
1978	Stora Kopparbergs Bergslags AB, Skutskär, Sweden	80/150	450	5,4	S + R
1979	Södra Sveriges Skogsägare, Mönsterås, Sweden	51/90	480	6,1	S
1980	Tofte Cellulosefabrikk A/S & Co, Hurum, Norway	40/40	490	8,4	S + R
1980	Alto Paraná, Argentina	100/120	485	6,5	S + R
1980	Philippine Wallboard Corp., Nasipit Lumber Co. Philippines	32/80	425	6,9	S
1980	Norske Skogindustrier, Skogn, Norway	36/14	450	5,8	S + R
1980	Fiskeby AB, Skärblacka	50/120	430	5,6	S + R
1981	Puerto Piray, Argentina	170/250	482	8,3	S + R
1981	AB Statens Skogsindustrier, Karlsborgs Bruk, Karlsborg	41/95	450	6,3	S + R

Note Between 1945—59 about 30 boilers were delivered to customers in Scandinavia.

S = Sloping tube grate
P = Plain grate

A = With Axon oven or cyclon furnace
R = Reciprocating grate

Postal addresses, telephone & telex numbers.

Götaverken Ångteknik AB

Head office Götaverken Ångteknik AB	Box 8734 S-402 75 Göteborg, Sweden	Telephone: 46-31-22 83 00 Telex: 2283 GOTAANG S
Office Maskinverken Götaverken Ångteknik AB Maskinverken Division Kallhäll	Fack S-175 02 Järfälla 2 Sweden	Telephone: 46-758-501 20 Telex: 19268 MASKIN S
Workshops Götaverken Ångteknik AB Göteborgsverkstaderna	Box 8734 S-402 75 Göteborg, Sweden	Telephone: 031-22 83 00 Telex: 2283 GOTAANG S
Gotaverken Ångteknik AB Gavleverkstäderna	Upplandsgatan 19 Box 227 S-801 04 Gävle, Sweden	Telephone: 026-12 95 80
Gotaverken Ångteknik AB Karlshamnsverkstaderna	Stillerydsområdet S-292 00 Karlshamn, Sweden	Telephone: 0454-150 10
Subsidiaries Gotaverken Angteknik do Brasil	Rua Prof. Arthur Ramos, 183 conj. 52 01454 São Paulo, Brazil	Telephone: 011-813 26 91 Telex: 1123380 GKEN BR
Gotaverken Ind. e Com. Ltda (office and workshops) (part owned)	Rod. Pres. Dutra, km 135 Cx. P. 166 27500 Resende-RJ Brazil	Telephone: 0223-54 27 55 Telex: 223158 GKEN BR
Gotaverken Energy Systems Ltd	111 Railside Road Suite 300, Don Mills Toronto, Ontario M3A 1B2 Canada	Telephone: (416) 441-2421 Telex: 06-966773
Sunrod AB	Fack S-175 02 Järfälla 2, Sweden	Telephone: 0758-501 20 Telex: 19268 MASKIN S
Maskinverken Norge A/S	Bygdoy Allé 119 Oslo 2, Norway	Telephone: 02-55 09 80 Telex: 19943 MANOR N

BABCOCK & WILCOX

Names and addresses of foreign sales representatives

Josueth Gonzalez Cia. Ltd.
Apartado 4870-CCl
Quito, Ecuador

Middle East Trading & Engineering Company
2, Sherif Pacha Street
Lewa Building
Cairo, Egypt

P.T. Fajar Mas Murni
P. O. Box 195/KBY
Jakarta, Selatan
Indonesia

JISCO Co.
European Operations
35 Bridge Street
Hitchen
Hertfordshire SG5 2DG
United Kingdom

Aravah A.T.I., Ltd.
P. O. Box 14051
Tel Aviv 67136 Israel

Sepro, S.R.L.
Via Turati, 26
20121 Milano, Italy

C. Itoh & Co., Ltd.
CPO Box 136
Tokyo, Japan

Whashin Industrial Co.
C.P.O. Box 1121
Seoul, Korea

Al Nawasi Trading Company
P. O. Box 3204
Safat, Kuwait

Modern Arab Construction (U.K.) Ltd.
P. O. Box 2BN
London WIA 2BN, England

BABCOCK & WILCOX

Names and addresses of foreign sales representatives (continued)

Corporacion Tecnica de Comercio S.A.
Casilla 1537
Lima, Peru

Engineering & Construction Corp. of Asia
MCC P. O. Box 967
Makati, Metro Manila, Philippines

Portilla Corporation
G.P.O. Box 4128
San Juan, Puerto Rico 00936

Modern Arab Contractors
P. O. Box 172
Al-Khobar, Saudi Arabia

Energesa
General Sanjurjo, 55
Madrid-3, Spain

Steam S.A.
Avenue de Jurigoz 10
CH-1006 Lausanne
Switzerland

Fortune Engineering & Trading Co., Ltd.
P. O. Box 22016
Taipei, Taiwan
Republic of China

Phothi-Ratana Engineering & Pharmaceutical Co., Ltd.
P. O. Box 11-1074
Bangkok, Thailand

Fenni-Gama Ic Ve Dis Ticaret A.S.
Kizilay Emek Ishani Kat 18
Ankara, Turkey

The Marketing & Construction Co.
P. O. Box 750
Abu Dhabi, United Arab Emirates

Parker Associates
Intourist Hotel
No. 1 Gorky Street
Moscow, USSR

Babcock & Wilcox de Venezuela S.A.
Apartado 142111
Caracas 101, Venezuela

BABCOCK & WILCOX

Names and addresses of foreign sales representatives (continued)

Babcock & Wilcox de Venezuela S.A.
Apartado 142111
Caracas 101, Venezuela

NAME USDA/FS AID
DATE 8/6/80

SUBJECT: EQUIPMENT SUPPLIERS
BOILERS

NWPC 231014

MANUFACTURER: Conterma - Constructora Industrial E TermoTecnica S.A.
Rua Capote Valente, 1324 & 1344
ZP 9 - Caixa Postal, 2519
Sao Paulo, Brazil
(55) (11) 65-7101 & 65-7104

EQUIPEMNT TYPE(S): Wood Fired Boilers

MANUFACTURER: Companhia Brasileira De Caldeiras E Equipamentos Pesados
Praca Joao Mendes 42-18-19.0 Andar
Sao Paulo, Brazil
(55)(11) 37-8591 thru 37-8595

EQUIPMENT TYPE(S): Wood Fired Boilers

NAME USDA/FS AID
DATE 8/5/80

SUBJECT: EQUIPMENT SUPPLIERS NWPC 231014
Boilers

MANUFACTURER: Energy Division
Zurn Indutries Inc.
1422 East Avenue
Erie, PA 16503
(814) 4526421

Rebecca Stephens
International Marketing Associate

EQUIPMENT TYPE(S): See Sheet 2

APPLICATIONS: See Sheet 2

CAPACITY RANGE: See Sheet 2

REFERENCE: Form No. SB-62 SB-74 SB-81
SB-68 SB-76 SB-83
SB-71 SB-80

FOREIGN AGENCIES: Licensees: Argentina, Canada, India, Brazil, Denmark, Peru
Representatives: Australia, Israil, Taiwan, Venezuela, Costa Rica, Philippines Turkey

Send all inquiries to the attention of Rebecca Stephens, Energy Division for appropriate referral

NWPC 231014

NAME USDA/FS AID
DATE 8/7/80

SUBJECT: EQUIPMENT SUPPLIERS
Boilers

MANUFACTURER: Gotaverken Energy Systems Ltd.
111 Railside Road, Suite 300
Don Mills (Toronto) Ontario, Canada M3A 1B2
(416) 441-2421 Tlx. 06-966773

EQUIPMENT TYPE(S): Wood Fired Boilers

DESIGN FEATURES: Conventional equipment

CAPACITY RANGE: 3.2 to 50.4 kg/s (25,000 to 400,000 lbs/hr) steam

PERTINENT INSTALLATIONS: See Sheet 2 of 3

REFERENCE: Product & Contact Guide
List of Installations
Industrial Steam Boilers
Efficient Firing of Wet Bark & Wood Waste

NWPC file
1 copy each

FOREIGN AGENCIES: See Sheet 3 of 3

EQUIPMENT SUPPLIERS

BOILER

E. KEELER CO.

238 West Street
Williamsport, Pennsylvania 17701
(717) 326-3361
TLX 84-1435

Contact: Robert E. Lants
Chief Sales Engineer

Wood Fired Boilers - 1.26 kg/S (10,000 PPH) to 31.5 Kg/S (250,000 PPH) of steam and up to 6205 Kpa (900 psig) design pressure and 440 degrees C, (825 degrees F).

Foreign Sales Offices

Licensees:

Canadian Vickers Ltd.
5000 Notre Dame East
Montreal, Canada HIV 2BR

Gresham's (Eastern) Limited
P. O. Box 5020
4 West Whart Khawja House
Karachi, Pakistan

Termoelectrica S.R.L.
LaValle 623 - Of. 108
1 er Piso
Buenos Airea. Argentina
South American

Sales Offices:

Importanciones Representaciones del Pacifico, S.A.
Camana 851 - Of. 1102
P. O. Box 6016
Lima, Peru, South America

Sigdo Koppers, S.A.
Renato Sanchez 3859
Casilla 13960
Santiago de Chile, South America

Misco, S.A.
Dr. Jimenez No. 33
Mexico 7, D.F.

Alfredo Raventos Representaciones
P. O. Box 60376
Caracas, Venezuela
South America

RILEY STOKER CORPORATION

Contact: Marketing Department

P. O. Box 547
Worcester, Massachusetts 01613
(617) 852-7100
TLX 92-0426 CABLE: RILEY

Boilers - Field erected only. Grates - Traveling and Water Cooled. Fuel Spreaders and Fuel Feeders. Steam generating equipment furnished with specialized fuel burning equipment designed to fire a wide variety of refuse, including municipal trash.

Applications: Burns bagasse, bark, wood-wastes, coffee grounds, nut hulls, rice hulls, corn cobs, sunflower seed hulls, rubber wastes, leather scrap, cork scrap, paper wastes, municipal wastes, (prepared and unprepared).

NAME USDA/FS AID
DATE 7/16/80

SUBJECT: EQUIPMENT SUPPLIERS
Boilers

Job No. 231014

MANUFACTURER: E. Keeler Co.
238 West Street
Williamsport, PA 17701
(717) 326-3361 Tlx. 84-1435

Robert E. Lantz
Chief Sales Engineer

EQUIPMENT TYPE(S): Wood Fired Boilers

CAPACITY RANGE: 1.26 kg/s (10,000pph) to 31.5 kg/s (250,000pph) of steam & up to 6205 kpa (900 psig) design pressure & 440 degrees C (825 degrees F)

FOREIGN AGENCIES: See Sheet 2 of 2

E. KEELER CO.

FOREIGN AGENCIES: Licensees

Canadian Vickers Ltd.
5000 Notre Dame East
Montreal, Canada HIV 2BR

Gresham's (Eastern) Limited
P. O. Box 5020
4 West Wharf Khawja House
Karachi, Pakistan

Termoelectrica, S.R.L.
LaValle 623 - of. 108
1 er Piso
Buenos Airea, Argentina
South America

Sales Offices:

Importanciones Representaciones del
Pacifico, S.A.
Camana 851 - Of. 1102
P. O. Box 6016
Lima, Peru, South America

Sigdo Koppers, S.A.
Renato Sanchez 3859
Casilla 13960
Santiago de Chile, South America

Misco, S.A.
Dr. Jimenez No. 33
Mexico 7, D.F.

Alfredo Raventos Representaciones
P. O. Box 60376
Caracas, Venezuela
South America

NAME USDA/FS AID
DATE 7/28/80

SUBJECT: EQUIPMENT SUPPLIERS
Boilers

NWPC 0680

MANUFACTURER: Riley Stoker Corporation
P.O. Box 547
Worchester, MA 01613
(617) 852-7100 Tlx. 92-0426
Cable: RILEY

EQUIPMENT TYPE(S): Boilers - Field Erected only
Grates - Traveling & Water Cooled
Fuel Spreaders
Fuel Feeders

DESIGN FEATURES: Steam Generating Equipment Furnished With Speacialized Fuel Burning Equipment Designed To Fire A Wide Variey of Refuse, Including Municipal Trash.

APPLICATIONS: Burns Bagasse, Bark, Wood Wastes, Coffee Grounds, Nut hulls, Rice hulls, Corn Cobs, Sunflower Seed Hulls, Rubber Wastes, Leather Scrap, Cork Scrap, Paper Wastes & Municipal Wastes (Prepared & Unprepared)

CAPACITY RANGE: Biomass Alone: 6.3 to 63 kg/s (50,000 to 500,000pph) steam with auxiliary (oil, natural gas, coal) fuel: Size limited.

PERTINENT INSTALLATIONS: Bagasse - Florida Sugar Mill
Coffee Grounds - Southern U.S.A. Coffee Plant
Wood Waste - Montana Forest Products Plant

REFERENCE: Riley Brochures: Refuse Fuel Burning Equipment — NWPC file 1 copy ea
Traveling Grates for Cool Firing

FOREIGN AGENCIES: Riley has licensees and Representatives throughout the free world. All inquiries to be directed to the Main Office in Worcester, MA.

BOILERS

RILEY STOKER CORPORATION - Continued -

Capacity Range: Biomass alone - 6.3 to 63 kg/s (50,000 to 500,000 PPH) steam with auxiliary (oil, natural gas, coal) fuel. Size unlimited.

Pertinent Installations: Bagasse - Florida Sugar Mill; Coffee Grounds - Southern USA Coffee Plant. Wood-waste - Montana Forest Products Plant

Foreign Sales Offices

Riley Stoker has licensees and representatives throughout the free world. All inquiries to be directed to the main office in Worcester, Massachusetts.

TAKUMA CO., LTD.
Eitaro Bldg
2-5 Nihonbashi 1-Chome
Chuo-Ku, Tokyo, Japan
(30) 271-2111
TLX 0222-2878 Cable: TAKUMA TOKYO

Contact: Nobuhiro Kobayashi
International Department

Wood Fired Boilers.

WEISS USA INFORMATION CENTER
P. O. Box 8
Woxall, Pennsylvania 18979
(215) 234-8000
TLX 83-6455

Contact: Karl H. Middelhauve
Consultant

Mini Boilers. Burns sanderdust, sawdust, shavings, chips, solid cutoffs (dry or green) solid rippings (dry or green up to 4 ft. long), unhogged bark, paper, walnut shells, bagasse, tobacco dust, spent coffee grinds.

Capacity: 40 to 160 hp.

NAME USDA/FS AID
DATE 8/6/80

SUBJECT: EQUIPMENT SUPPLIERS
Boilers

MANUFACTURER: Takuma Co., Ltd.
Eitaro Bldg.
2-5 Nihonbashi 1-Chome
Chuo-Ku, Tokyo, Japan
(03)271-2111 Tlx. 0222-2878 Takuma J
Cable: Takuma Tokyo

Nobuhiro Kobayashi
International Depart.

EQUIPMENT TYPE(S): Wood Fired Boilers

NAME USDA/FS AID
DATE 10/21/80

SUBJECT: EQUIPMENT SUPPLIERS
Boilers

MANUFACTURER: Weiss USA Information Center
P. O. Box 8
Woxall, PA 18979
(215) 234-8000 Tlx. 83-6455

Karl H. Middelhauve
Consultant

EQUIPMENT TYPE (S): Mini Boilers

APPLICATIONS: Burns sanderdust, sawdust, shavings, chips, solid cutoffs (dry or green), solid rippings (dry or green up to 4 ft. long), unhogged bark, paper, walnut shells, bagasse, tobacco dust, spent coffee grinds.

CAPACITY RANGE: 40 to 160 hp

REFERENCE: Brochure

NWPC File
1 c/c

S T O K E R S

NAME USDA/FS AID
DATE 7/25/80

SUBJECT: EQUIPMENT SUPPLIERS STOKERS

MANUFACTURER: American Fyr-Feeder Engineers
P.O. Box 285 1265 Rand Road
Des Plaines, IL 60016
(312) 298-0044

Victor A. Gauger
President

EQUIPMENT TYPE(S): (1) Wood Fuel Burning Boiler System
(2) Multiple Spreader Coal Stoker

DESIGN FEATURES: (1) Standard System Starts at Silo Inlet and Ends at Pollution Control and Draft Equipment Outlet

APPLICATIONS: (1) Burning of Hogged Wood, Planer Shavings, Sawdust, Sander Dust, Wooden Pallets, Bark, Corn Cobs, Bagasse, Nut Hulls and Pecan Shells

CAPACITY RANGE: 196 KW (20HP) to 19.6 MW (200HP)

PERTINENT INSTALLATIONS: See Sheet 2 of 2

REFERENCE: Unnumbered American Fyr-Feeder Brochures NWPC file 1 copy each

FOREIGN AGENCIES: None

NAME USDA/FS AID
DATE 8/20/80

SUBJECT: EQUIPMENT SUPPLIERS
Stokers

MANUFACTURER: Detroit Stoker Co.
P.O. BOX 732 1510 East First Street
Monroe, MI 48161
(313) 241-9500
TWX: 810-231-7293

Eddie A. Taylor
International Sales Manager

EQUIPMENT TYPE(S): (1) Stoker Systems for Burning Biomass
(2) Conveying Systems to Convey Solid Fuel & Ash Residue

DESIGN FEATURES: (1) Detroit Roto Grate-Continuously Forward Traveling Grate Stoker Detroit Roto Stoker-Intermittent Dumping Grates or Vibrating Conveying Grates
(2) Conveying Systems-Pneumatic & Hydraulic
All Equipment is Manufactured on an Individual Job Basis

APPLICATIONS: Burn Bark, Wood Waste, Shavings & Saw Dust, Bagasse, Oat Hulls, Coffee Refuse, Industrial Refuse, Municipal Refuse & Garbage

CAPACITY RANGE: Stoker Equipment can burn 1 to 25 kg/s (4 to 100tons/h of prepared wood or waste products.

REFERENCE: Detroit Stoker Bulletins No. 590 — NWPC file
No. 1105 — 1 copy each

FOREIGN AGENCIES: Licensees:
Babcock Power Limited - Crawley, England
Babcock Australia - Sydney, Australia
Babcock-Hitachi K.K. - Tokyo, Japan

B U R N E R S

NAME USDA/FS AID
DATE 8/5/80

SUBJECT: EQUIPMENT SUPPLIERS
Burners

MANUFACTURER: Coen Company, Inc.
1510 Rollins Road
Burlinggame, CA 94019
(415) 697-0440 Tlx. 03-4337
Cable: Coen Burner

H. N. Lockwood, JR.
Manager
International Sales & Marketing

EQUIPMENT TYPE(S): Industrial Burner Systems Which Burn All Types of Biomass Fuels in Addition to Coal, Gas, & Oil

APPLICATIONS: Combustion of Air Conveyed Dry Solid Fines:

Sander Dust	Ground Wood Waste
Bagasse Fines	Rice Hull Fines
Sunflower Seed Fines	Other Finely Ground Organic Fibers

CAPACITY RANGE: 3 to 60 MW (10 to 200 million BTU per hour) since Burner Biomass Firing Systems

REFERENCE: Bulletins: SF-66
WW-74

NWPC file
1 copy each

FOREIGN AGENCIES: See Sheets 2 thru 4

NAME USDA/FS AID
DATE 8/5/80

COEN Company Inc.
Combustion Engineer and Manufacturers Since 1912
1510 Rollins Road, Burlingame, CA 94010

OVERSEAS AGENTS AND LICENSEES
(Including Territorial Limits)

NAME	ADDRESS	WIRE/TELE.
ARAB REPUBLIC OF EGYPT (Sales) (Arabic Countries of Middle East)		
Coen Company (Middle East Oprns) Mohsen El Nimr	43 El Fath Street Fleming, Alexandria, Arab Republic of Egypt	Ph:68684-50527 Telex: 54053 COMAL:
CENTRAL, SO. AMERICA (Sales) (Guatemala, Belize, El Salvador, Honduras, Nicaragua, Costa Rica & Panama (including Canal Zone)		
Wabash Power Equipment Co. Severin Caitung Richard Caitung Morton Stotsky	444 Carpenter Ave. Wheeling, IL 60090	Ph:312-541-5600 Telex: 28-2556
AUSTRALIA (Manufacturing)(Licensee) (Australia, Tasmania, and New Zealand)		
Trevor Boiler & Engr. Co. Eric Kottmann G. N. Gamble, Chief Engr.	Steel Street North Melbourne Victoria 3051, Australia	Ph:320-7977 Telex: Trevor AA 36745 CABLE: TREBORBROS (MELBOURNE)
BRAZIL (Manufacturing)		
Coen Combustao Industrial Ltda. T. H. (Skip) Pendle (Joint Venture)	Street Address: 21020 Rua Guatemala 222 Rio de Janeiro R.J. Brazil	PH: 021-270-7188 7339 Telex:2122623 MTEX BR CABLE: COENBURNER (Rio de Janei:

COEN COMPANY (continued)

NAME	ADDRESS	WIRE/TELE.
BRAZIL (Sales)		
Matex Comercio E Industria Ltda. Alfred Michahelles Paul Wollny	Mailing Address: Caiza Postal 759 CEP 20,000 Rio de Janeiro, R.J. Brazil Street Address: Avenida Rio Branco 25/18º CEP 20093 Rio de Janeiro, R.J. Brazil	Ph: (021) 233-9422 Telex: 2122623 MTEX BR& 2122997 CABLE: MATEX (Rio de Janeiro
CANADA (Sales) Western Provinces (British Columbia & Alberta)		Ph:604-254-0461 Telex:0451370
Industrial Process Heat Engineering, Ltd. Eric Panz(home:604-922-8852) Bob Lowden	680 Raymur Ave. Vancouver, B.C. V6A 2R1 Canada	
CANADA (Sales) Central Provinces (Ontario, Manitoba, Saskatchewan)	670 Progress Ave. Unit 6 Scarborough, Ont., M1H 3A4 Canada	
KV Combustion & Energy Systems, Ltd. Keith Veitch		Ph:416-439-7421 Telex: 06525181 (Ans. Back "KV COMB. TOR")
CANADA (Sales) Eastern Provinces (Quebec, New Brunswick, Newfoundland)		
Thermequip, Ltd. Ray P. Fairon, Pres. H. Paul Houle, V.P. Yvon Ainsley, Chief Engr.	8019 Rue Alfred Anjou, Que., H1J1J3 Canada	Ph:514-354-4811 Telex:05829636 (Ans. Back "THERMEQUIP MTI
ENGLAND (See United Kingdom)		
EGYPT (See Arab Republic of Egypt)		
FINLAND (Sales) Oy Algol, AB Leo-Pekka Toikka	Et. Ranta 8, Helsinki, 13 Finland	Ph: 12631 Telex: 121430 (Ans. Back "121430 ALGOL S

COEN COMPANY (continued)

FRANCE (Manufacturing)(Licensee)

Mecnique Generale Foyers Turbine H. Dibos Mr. Boudon, Pres.	143 Grande-Rue 92310, Sevres, France	PH: (33)534-20-03 Tlx. 204810 CABLE:"FOYERTURBI" (Paris) (Ans. Back "MGFT 204810F")

INDIA (Manufacturing)

Dalal Project Services, Ltd. J.D. Udeshi (Joint Venture)	86, Dr. Annie Besant Road Worli Naka Bombay 400018 India	Ph: 391891 Telex: 113108 DLCO I CABLE:"HYDROTHERM" (Bombay)

ITALY (Manufacturing)

Tecnofluid S.R.L. G.E. Cugnasca	Piazza Bernini 6 20133 Milano Italia	Ph: 230.579-236.04 .72

JAPAN (Manufacturing)(Licensee)
(Japan and Southeast Asia)

Nippon Furnace Kogyo Kaisha, Ltd. RyoichiTanaka, Pres. Shuzo Miyazaki, Director Toshiyoki Ochiai, Director	Post Office No. 230 No. 1-53, 2-Chome,Shitte Tsurumi-Ku Yokohama, 230 Japan	Ph: 581-1281(Yoko.) Telex:781-03822340 CABLE:"FURNACE" (YOKOHAMA) (Ans. Back 3822340 NFK J)

MEXICO (Manufacturing)
(Republic of Mexico)

Protherm de Mexico, S.A. Manuel Gardea Rivas	A. Ferrocarril Hidalgo No. 1030-A Mexico 14, D.F. Mexico	Ph: 905-577-3211 Telex: 01777479 PD MFME

THE NETHERLANDS (Manufacturing)
(ECC, excl. France, Italy & Spain)

de Jong-Coen, B. V. - Agent Jan deJong A.W. Spoormaker Jan Kentson, V.P. Engr. (Joint Venture)	MAILING ADDRESS: Postbus 5 3100AA Schiedam, Netherlands Street Address; 'S Gravelandseweg 390 3125BK Schiedam, Netherlands	Ph: 010-37-61-66 Telex: 24372DEJON:

PERU (Sales)

H. G. Multitrade, Inc. Edgar Gerber	P.O. BOX 01-4781 Miami, Florida 33101	PH: 305-856-9603 9604 Telex:519616

COEN COMPANY (continued)

PHILIPPINES (Sales) (Republic of the Philippines) The Edward J. Neel Co. E. S. Ocampo	P.O. Box 1332 - MCC (325 Buendia Ave. co. Malugay) Makati, Rizal, Republic of the Phil- ippines	Ph: 742-5434 Telex: RCA 722 2077 Globe-Mc. 7420234 CABLE: "NELED" (Manila)
PUERTO RICO, JAMAICA, VIRGIN ISLANDS KAG Industries Scott Gallagher	141 E. 44th St. Room 501 New York, NY 10017	Ph: 212-867-0470 Telex: 214305
SPAIN (Manufacturing) (Spain & Portugal) Vasaco, S. A. Fernando Maluenda	Avda. Gmo. Franco, 466 Barcelona, 8 Spain	Ph: 228.90.05 CABLE: "VASACO" (Barcelona)
UNITED KINGDOM (Sales) de Jong-Coen, B.V.-Agent Paul Winger	"Beachwood" 33, Mount Close, Pound Hill Three Bridges Sussex, England	Ph: Crawley (0293) 882379 CABLE: (Use Full address)
VENEZUELA (Sales) (Venezuela, Curaco & Aruba Islands)	Apartado No. 60163 (Av. Francisco de Miranda Edif. Easo., Oficina 6L) Caracas, Venezuela	Ph: 33-43-65 Telex: 395 23218 CABLE: "SERVISEC" (CARACAS) (Ans. Back "23218 PEMCA")

NAME USDA/FS AID
DATE 7/30/80

SUBJECT: EQUIPMENT SUPPLIERS
Burners

MANUFACTURER: Guaranty Performance Co., Inc.
P.O. Box 748 1120 East Main
Independence, KS 67301
(316)331-0020

Andrew Livingston
President

EQUIPMENT TYPE(S): (1) Suspension Fire Solid Fuel Burners
(2) Package Plants to Manufacture Densified organic (Biomass) Fuels

DESIGN FEATURES: (1) Burners Burn Biomass Fuels in a temperature controlled situation providing non-voltile & ash removal in an integral cyclonic furnace chamber.

APPLICATIONS: (1) Burners Systems Deliver Clean Combustion Gases at Approvimately 930°C (1700°F) for Industrial Processes requiring thermal heat input.

(2) Package Plants Produce Fuel Pellets from:

Tree Bark	Rice Hulls	Wood
Wheat Straw	Peanut Hulls	Mesquite
Corn Cob & Stock	Bagasse	Peat
Animal Manure	Sewage Sludge	Municipal Waste

CAPACITY RANGE: (1) 4.4 to 17.6 MW (15 to 60 million BTU/hr)
(2) 136 to 455 Mg per day (150 to 500 tons/day) of pellet production.

PERTINENT INSTALLATIONS: See Sheets 2 & 3

REFERENCE: GUARANTY Performance Bulletins:		NWPC file
	180	2 copies
	277	2 copies
	477	3 copies

FOREIGN AGENCIES: NONE

MANUFACTURER: Peabody Gordon-Piatt, Inc.
P.O. Box 650
Winfield, KS 67156
(316)221-4770 Tlx 417-452

L. W. Halstead
Market Manager

EQUIPMENT TYPE(S): See Sheet 2

DESIGN FEATURES: See Sheet 2

APPLICATIONS: See Sheet 2

CAPACITY RANGE: See Sheet 2

REFERENCE: See Sheet 2

FOREIGN AGENCIES: See Sheet 3

PEABODY GORDON-PIATT

2. a. Solid Fuel burners for hogged material.

   b. Solid Fuel burners for dust-type fuels.

   c. Metering Bins, live bottom type.

   d. Control Systems for burner systems.

   e. Storage Silo, Steel tank type.

   f. Induced Draft Fan and Mechanical Collector Modules.

   g. Job designed Conveying Equipment from standard components.

   Items 2a thru 2d manufactured in U.S. only.

   Items 2e thru 2g may be of 'in-country' manufacture.

   Must meet PG-P specifications.

3. Equipment is conventional. All items manufactured to orders from component parts inventoried or bought.

5. Solid fuel burner works with wood, plant waste, and agricultural by-products, including corncobs, peanut shells, and spent tea leaves.

6. Burner Sizes: 3.7 to 47.5 GJ (3.5×10^6 to 45×10^6 Btu)

   Metering Bins:

Cu metre	Cu Ft
0.9	30
5.7	200
9.2	325

   Silos up to 283 cu metre (10,000 cu ft) capacity.
   Fans and collectors to suit gas flows from combustion equipment.

8. 2a - SFA Burner Dimensional Data
   2b - SFD Burner Dimensional Data

PEABODY GORDON-PIATT

2c - WB3D-1928 Metering Bin Assemblies
2f - WB2D-2266 Multicone Collector/I.D. Fan Arrangement
SF Burner brochure
SF System brochure

9. Foreign Sales Offices:

a. G. P. Burners Ltd.
25 Taleworth Road
Ashtead, Surrey, KT21 2PT
England
Tele: 037-22-73875

b. Hovin, B.V.
Deltsestraatweg 150
Delfgauw
The Netherlands
Tele: 015-560167

c. Peabody Gordon-Piatt (Canada)
Div. of Peabody International (Canada) Ltd.
P. O. Box 292
REXDALE, Ontario, Canada M9W5LI
Tele: 416-743-4401

d. Andrew Barton & Co., Pty. Ltd.
312 Ipswich Rd.
Annerly, 4103, Queensland, Australia
Tele: 07-391-1921

NAME USDA/FS AID
DATE 10/1/80

SUBJECT: EQUIPMENT SUPPLIERS
Burners

MANUFACTURERS: Rettew Associates, Inc.
Box 65, North Sheridan Road
Newmanstown, PA 17073
(215)589-2024

W. B. Henderson
President

EQUIPMENT TYPE(S): Industrial Wood Burning Furnaces

APPLICATIONS: Burn wood waste and other combustibles for area heating and drying applications.

CAPACITY RANGE: 150MW to 900MW (500,000 BTU/hr to 3,000,000 BTU/hr)

REFERENCE: Rettew Brochure and Price List

NWPC file
1 copy

G R I N D E R S

NAME USDA/FS AID
DATE 7/17/80

SUBJECT: EQUIPMENT SUPPLIERS
GRINDERS

Sheet of

MANUFACTURER: Gruendler Crusher & Pulverizer Co.
2915 North Market Street
St. Louis, MO 63106
(314) 531-1220 Tlx. 44-7415
Cable: GRUPULCO

Charlie Dilly
Sales Manager

EQUIPMENT TYPE(S): Pulverizers, Crusher, Shredder-Cutters, Grinders& Wood & Bark Hogs

APPLICATIONS: Equipment used in the wood, pulp, paper & Bagasse Fields for energy conversion.

PERTINENT INSTALLATIONS: See Sheet 2

REFERENCE: Gruendler Bulletins 1001, MR-173B, 942, 155-7, 915-1 & RS-6
NWPC file - 1 copy of each

FOREIGN AGENCIES & UNITED STATES REPRESENTATIVES: See Sheets 3 thru 6

Adams Brothers, Inc. 750 Eleventh Street, N.W. Atlanta, Georgia 30318	R. D. Adams R. B. Adams Phil Colter (Birmingham)	404-872-8881 Telex: 54-2606 205-979-1931
Alaska Expediters, Inc. 3685 Arctic Blvd. Anchorage, Alaska 99503	Sam McDowell	
Anziel Pty., Ltd. #3 Bowen Crescent Melbourne, 3004, Australia	B. E. Hughes	267-1333 Telex: 31308
Anziel Limited 32 Hastie Avenue P. O. Box 59-054, Mangere Bridge Mangere, Auckland, New Zealand	P. A. Judkins	663-969 Telex: NZ-2473
APPCO Buckeye Plaza, Suite 310 3301 Buckey Road Atlanta, Georgia 30341	Richard Pharr	404-451-7447
Arizona Conveyor Exchange P. O. Box 50564 Tucson, Arizona 85703	Robert A. French	602-888-3940
Hugh Boyd & Associates 5905 S. Jamestown Avenue Tulsa, Oklahoma 74135	Hugh Boyd	918-742-5714
Centennary Central, Inc. 1750 South Brentwood Blvd. Suite 657 St. Louis, Missouri 63144	Spencer C. Wolling	314-961-7445
Chisholm Machinery Sales Limited P. O. Box 245 Niagara Falls, Canada L2E 6T3		416-356-1119
Crushing Systems, Inc. P. O. Box 2315 Winter Haven, Florida 33880	John Williams	813-324-4326
CU AL Engineering Pty. Ltd. 2 Enfield Road Durban, Republic of South Africa	E. D. Bailey	
Davies Industrial Services, Inc. P. O. Box 8, Amherst Branch Buffalo, New York 14226	Bill Davies	716-838-6697

NAME USDA/FS AID
DATE 8/21/80

SUBJECT: EQUIPMENT SUPPLIERS
Grinders

MANUFACTURER: HOBBS International, Ltd.
1100 Holland Road
Suffolk, VA 23434
(804)529-0231 Tlx: 82-3600
Cable: HOADEN SUFK

Harold U. Blythe

EQUIPMENT TYPE(S): Model 855 Flow Control Metered Feeding Machine
Hammer Mills or Grinders
Dual Chain Conveyors
Rubber Belt Conveyors

APPLICATIONS: Processing & Transporting Wood Chips, Sawdust, Tree Bark & Other Wood Products

PERTINENT INSTALLATIONS: Hobbs Wood Processing & Agricultural Machinery in use in 31 Contries outside the USA

REFERENCE: Un-numbered Brochures

FOREIGN AGENCIES: See Sheet 2 of 2

HOBBS

HOBBS INTERNATIONAL LTD.

FOREIGN AGENCIES: Exclusive distributors:

Australia - The Peanut Marketing Board
P. O. Box 26
Kingaroy, Qld. 4610

South Africa - Vetsak, Ltd.
P. O. Box 80
Bothaville, OFS 9660

Venezuela - Keroma, S.A.
Apartado 68268 (Altimira)
Caracas, Venezuela

Sudan - Sarkis Izmirlian Corp.
P. O. Box 112
Khartoum, Sudan

NAME USDA/FS AID
DATE 7/8/80

SUBJECT: EQUIPMENT SUPPLIERS
Grinders

MANUFACTURER: Schutte Pul erizer Co., Inc.
61 Depot Street
Buffalo, NY 14240
(716) 855-1555 Tlx./TWX - None

EQUIPMENT TYPE(S): Wood Grinder Hammer Mills, Trim Scrap Grinders, Bark Grinders, Hogerizers

APPLICATIONS: Processing Wood Shavings, Chips, Bark, Hogged Scraps for Boiler fuel

			NWPC file
REFERENCE:	Schutte:	Bulletin No. HW 273R	1 copy
		Form No. HW 169 & 169 Supplement	1 copy
		Form No. SP280	1 copy
		Form No. HO 380	1 copy

FOREIGN AGENCIES: NONE

NAME USDA/FS AID

DATE 7/16/80

SUBJECT: EQUIPMENT SUPPLIERS
Grinders

MANUFACTURER: Williams Crusher International, Inc.
2701 North Broad Way
St. Louis, Mo 63102
(314)621-3348

Harold J. Groves
International Sales

EQUIPMENT TYPE(S): Machines for grinding & drying wood products

CAPACITY RANGE: 15KW (20hp) to 1.5 MW (2000hp)

REFERENCE: Williams Bulletins 844, 845, 846, 871, 889, 924, 944 & 954
NWPC file - 1 copy each

FOREIGN AGENCIES: None

C O N V E Y O R S

NAME USDA/FS AID
DATE 7/17/80

SUBJECT: EQUIPMENT SUPPLIERS
Conveyors

MANUFACTURER: Atlas Systems Corp.
P.O. Box 11496
East 6416 Main Avenue
Spokane, WA 99211
(509) 535-7775

W. B. Hickman
Executive Vice President

EQUIPMENT TYPE(S): Storage and Retrieval System for Fibrous Type Bulk Materials

DESIGN FEATURES: Retrieves Material from Perimeter of the Pile

PERTINENT INSTALLATIONS: California, Idaho, Illinios, Iowa, Michigan, Missouri, New York, Oregon, Washington, Wisconson and British Columbia, Canada, Australia, Japan and New Zealand

REFERENCE: Atlas Catalog

NWPC file
1 copy

FOREIGN AGENCIES: Licensee:

Hitachi Metals, Ltd.
2-16 Marunouchi, Chiyoda-Ku
Tokyo, Japan
Telephone: Tokyo (211) 5311 Tlx. TK 4494
Cable: "Hitachimetal Tokyo"

NAME USDA/FS AID
DATE 7/25/80

SUBJECT: EQUIPMENT SUPPLIERS
CONVEYORS

MANUFACTURER: FMC Corporation
Material Handling Systems Division
Box 202 3400 Walnut Street
Col:.ar, PA 18915
(215)822-0581 Tlx. 84-6491
Cable: FMC LBMHS Cola

EQUIPMENT TYPE(S): General Material Handling System

APPLICATIONS: Bagasse, Cane, Coal, Log, Paper & Pulp, Sugar, & Wood Chip Handling Systems

CAPACITY RANGE: Medium to High Capacity Size Range

REFERENCE: FMC Directory
FMC Material Handling Systems Brochure — NWPC file 1 copy each

FOREIGN AGENCIES: See Sheet 2

FMC Corporation Material Handling Systems Division

Operations and Offices

Division Headquarters:
3400 Walnut Street
Colmar, PA 18915
Phone: (215) 822-0581
Telex: 846-491

Major Plant Operations and Sales Offices:

MHS Fairmont
1801 Locust Avenue
Fairmont, WV 26554
Phone. (304) 366-6550
Telex: 88429

MHS Canada
1960 Eglinton Avenue E
Scarboro, Ontario, Canada
Mail Box 17_, Station H
Toronto, Ontario, Canada M4C 5H9
Phone: (416) 750-4400
Telex. 06 963539

FMC do Brasil, S.A.
Divisao de Sistemas e
Equipamentos Mecanicos
Rua Frederico Esteban Junior
230 V. Albertina
Caixa Postal, 7101, CEP 02357
Sao Paulo, S.P. Brazil
Phone: 203-4111
Telex: 1122560

Area Sales Offices:

Atlanta
Buckeye Plaza, Suite 211
3301 Buckeye Road, N.E.
Atlanta, GA 30341
Phone (404) 455-8123

Chicago
1701 South First Avenue
Maywood, IL 60153
Phone (312) 865-8700 (Maywood)
(312) 379-8905 (Chicago)

Denver
Schloss & Shubart Inc
1626 Wazee Street
Denver, CO 80202
Phone. (303) 629-1551
Telex: 45 686

Detroit
Livonia Pavilion East
29200 Vassar
Suite 820
Livonia, MI 48152
Phone (313) 476-2323

Edmonton
10548—82nd Avenue
Edmonton, Alberta, Canada T6E 2A4
Phone (403) 433-5311

Geneva, Switzerland
17 Pierres-du-Niton
1207 Geneva, Switzerland
Phone 022-35-72-20
Telex 22 606

Houston
126 North Point Drive
Suite 110
Houston, TX 77060
Phone (713) 931-4939

Los Angeles
20800 South Belshaw Avenue
Carson, CA 90746
Phone (213) 638-1185

Montreal
11475 Cote de Liesse Road
Montreal, Quebec, Canada
H9P 1B3
Phone: (514) 631-8505
Telex: 05 267491

New York
71 Grand Avenue
Palisades Park, NJ 07650
Phone. (201) 945-1994

San Francisco
One Edwards Court
Suite 206
Burlingame, CA 94010
Phone: (415) 348-5721
Telex: 33 1460

Affiliates and Licensees:

Ataka Construction and
Engineering Co., Ltd
Environmental Equipment Div
10, 4-Chome
Sueyoshibashidori,
Minami-Ku
Osaka, Japan
Phone (06) 244-1161
Telex: 0522-2068
Cable: ATAK OJ

Boudin & Blin
02300 Chauny (Aisne)
France
Phone: (23) 52-0781
Telex Boublic 150647F

Comau Industriale, S.p.A.
10092 Bienasco
Torino, Italy
Phone 340 332
Telex 21105

FMC—Filsan
Equipamentos Para
Sacramento, S.A
Av Engenheiro Eusebio
Stevaux, 873
Caixa Postal, 3070
Sao Paulo, S.P. Brazil
Phone 246-8344
Telex 24370FMCF BR
Cable FILSANASA

FMC/Link-Belt Mexicana, S.A.
de C.V
Km 14 Antigua Carretera
Mexico-Pachuca
Apartado Postal No. 74
Santa Clara, Edo. de Mexico
Mexico
Phone 5-69-23-22
Telex 017-72-483
Cable LINBELMEX, MEXICO

FMC South Africa, Ltd
Industry Road, New Era
Box 287
Springs 1560
Transvaal,
Republic of South Africa
Phone 56-1411
Telex 8055C
Cable LINKBELT SPRINGS

FMC Venezuela, Ltd
A Subsidiary of FMC Corporation
3400 Walnut Street
Colmar, Pennsylvania 18915
Phone (215) 822-0581
Telex 846-491

Mabor-Manutention, S.A.
2, rue du Raidillon,
78230
Le Pecq (Yvelines)
France
Phone: 958-85-77
Telex: 842-690958

Malco Industries, Limited
Box 41
Marrickville, New S. Wales
2204
Australia
Phone: 560-8144
Telex MALCO AA 20471
Cable MALCOIND, SYDNEY

Maquinas Pirantininga
Rua Rubiao Junior, 234
Caixa Postal, 4060
Sao Paulo, S.P. Brazil
Phone: 93-6181
Telex 391-1122481

Tarnos
Rosa de Silva 25
Madrid 20, Spain
Phone: 270 88 07
Telex 83143208
Cable: TAR E

NAME USDA/FS AID
DATE 7/17/80

SUBJECT: EQUIPMENT SUPPLIERS
Conveyors

MANUFACTURER: Kinergy Corporation
4821 Jennings Lane
Louisville, KY 40218
(502)964-5901 Tlx. 21-3012

George D. Dumbaugh
President

EQUIPMENT TYPE(S): Bin Activators; Activated Bins; Storage Pile & Rail Car Dischargers; Vibrating Feeders, Screens & Conveyors; De-Liquefying or Dewatering Screens.

APPLICATIONS: Withdrawal of Bulk Solids from Storage Bins or Piles

REFERENCE: Kinergy Catalog

NWPC file
1 copy

FOREIGN AGENCIES: Licensees:

Kinergy Division
AMI-Steego
2520 Haines Road
Mississauga, Ontario L4Y 1Y6
Canada
Mr. John Eckart
Phone: (416) 279-1930
Telex: 06961276

Boustead Australia Ltd.
CNR. South Road & Hillary St.
Braybrook, Victoria 3019
Australia
Mr. Barry Fogarty
Phone: 311 8133
Telex: AA 33188

NAME USDA/FS AID

DATE 7/17/80

SUBJECT: EQUIPMENT SUPLLIERS
Conveyors

MANUFACTURER: Mardee Corporation
1410 Northport Drive
Madison, WI 53704
(608)244-3331
Alan L. Andersen
President

EQUIPMENT TYPE(S): Wood Products Handling Systems

APPLICATIONS: Handling, Preparation & Storage of Hog Fuel, Trim Scrap, Chip, Bark & Sawdust

PERTINENT INSTALLATIONS: See Sheet 2

REFERENCE: Mardee Brochure

NWPC file
1 copy

FOREIGN AGENCIES: NONE

NAME USDA/FS AID
DATE 8/1/80

SUBJECT: EQUIPMENT SUPPLIERS
Conveyors

MANUFACTURER: Morbark Industries, Inc.
Box 1000
Winn, MI 48896
(517) 866-2381 Tlx. 227443

Jerry Morey
Marketing Manager

EQUIPMENT TYPE(S): Feller-Buncher Shears, Tree Chippers, Debarkers, Conveyors, Packaged Sawmill

APPLICATIONS: Harvesting & Material Handling of Biomass

REFERENCE:	NWPC file
Morbark Un-numbered Catalogs	
"Forest Management for America"	1 copy
"The Satellite Sauchip System"	1 copy
"Energy Unlimited U.S.A."	1 copy

FOREIGN AGENCIES: See Sheet 2

9. FOREIGN DEALERS

Schwedenmaschinen
Goess u. Starhemberg OHG
Villacher Strasse 1, Postfach 23
A-9011 Klagenfurt
Austria

M.T.M.
Zona Industriale
Villa di Enga
I-39044 Egna, Italy

Blackwood Hodge Lda.
Av. Infante D. Henrique, Lote 306
Cabo Ruivo - Lisboa 6
Portugal

B T Company
Postfack S-161 11 Bromma 11
Sweden

Comercial Urteaga Hnos. SA
PIO Loperena 22
Burlada (Navarra) Spain

Shingu Shoko Ltd.
Machinery Division
No. 4-2 2-chome, Toyo, Koto-ku
Tokyo, Japan

Morbark Pacific Ltd.
P.O. Box 1312
Rotorua, New Zealand

Mario Han, Director
Mario Han Y Asociados
Casilla (P.O. Box) 9028
Santiago, Chile

"F.G. License (Pty.) Ltd.
Sawmac Division
P.O. Box 391231
Bramley 2018, South Africa

NAME USDA/FS AID
DATE 8/18/80

SUBJECT: EQUIPMENT SUPPLIERS
Conveyors

MANUFACTURER: Rader Companies, Inc.
P.O. Box 20128
Portland, OR 97220
(503) 255-5330 Tlx. 36-0448
Cable: RADER-PORTLAND

Larry Sharp, Manager
Information & Communications

EQUIPMENT TYPE(S): See Sheet 2

APPLICATIONS: See Sheet 2

PERTINENT INSTALLATIONS: See Sheet 3

REFERENCE: See Sheet 4

FOREIGN AGENCIES: See Sheet 5 thru 7

2. Equipment Types:

Rader truck dumpers, dumping pits and infeed conveyors for collection and distribution; The Rader Disc Screen (RDS), Air Density Separator (ADS), Cyclo-Screen and Flotation Separators for scalping and classification; surge conveyors for controlled discharge; pneumatic and mechanical conveyors for handling, stock-piling and reclamation; rotary dryers for increased burning efficiencies; and direct boiler charging for energy generation.

5. Applications:

Process, handle and store wood residuals used as fuel.

8. References:

Title	NWPC File
Systems Catalog	1 copy
Energy Production from Wood Residues	2 copies
Rader Disc Screen	1 copy
Sand Air Filter	1 copy
Rader Stacker/Reclaimers	1 copy
Traveling Screw Bins & Reclaimers	1 copy
Rader/Thompson Rotary Dryer	1 copy
Rader Companies, Inc.	1 copy

RADER OFFICES

PAGE 1.

PARENT COMPANY
Beloit Corporation
Box 350
Beloit, Wisconsin 53511
Phone: (608) 365-3311
Phone: (800) 356-0778
Telex: 25-7458 & 7459

Rader Companies, Inc. (Corporate)
Rader Western, Inc.
Pulping Systems Division
Special Products Division
P.O. Box 20128
6005 N.E. 82nd Avenue
Portland, OR 97220
Phone: (503) 255-5330
Telex: 36-0448
Cable: Rader - Portland

Raderfab Construction, Inc.
P.O. Box 20997 (97220)
4441 N.E. 148th Avenue
Portland, OR 97230
Phone: (503) 256-9880

Rader Manufacturing, Inc.
1335 N.W. Northrup
Portland, OR 97209
Phone: (503) 243-2092

Rader Systems, Inc.
5350 Poplar Avenue
Suite 320
Memphis, TNN 38117
Phone: (901) 761-3390
Telex: 053-804

Rader Canada Ltd./Pacific Division
P.O. Box 65567 Postal Station "F"
Vancouver, B.C. Canada V5N 5K5
4360 Halifax Street
Burnaby, B.C., Canada V5C 3X4
Phone: (604) 299-0241
Telex: 043-54570

Rader Canada Ltd./Corporate
1127 West 14th Street
N. Vancouver, B.C., Canada V7P 1J9
Phone: (604) 980-5011

Rader Canada Ltd./Rader Canada Ltee.
P.O. Box 925, Ville St. Laurent
1200 Begin Street
Montreal, P.Q., Canada H4L 4W3
Phone: (514) 331-1200
Telex: 05 824609

Rader S.A.
18-20 Place de la Madeleine
F-75008 Paris, France
Phone: 742-93-69
Telex: 842-220828

Rader International Service Office
Am Konigshof 3 Postfach 120424
D-8400 Regensburg, West Germany
Phone: (0941) 58-255 and 54-270
Telex: 06-5684
Cable: Trarad-Germany

Rader do Brasil Transportes
Pneumaticos Limitada
Rua Tumiaru 285, IBIRAPUERA
Caixa Postal 30373
01051 Sao Paulo, S. P., Brazil
Phone: 544-1957, 70-1446, 70-1211

Radmark Engineering, Inc.(Pennsylvania)
P.O. Box 13267
Pittsburgh, PA 15243
1082 Bower Hill Road
Pittsburgh, PA 15243
Phone: (412) 279-3132

Radmark Engineering (U.K.) Ltd.
Phoenix House
Mansfield Road
Sutton-In-Ashfield
Nottinghamshire
England NG17 4HD
Phone: Mansfield (0623) 512512
Telex: 377606

Radmark Africa (Pty.) Ltd.
P.O. Box 995
Roodepoort 1725
Transvall, South Africa
Phone: 763-1421

Rader International AB
Krossgatan 34
S-162-26 Vallingby, Sweden
Phone: 89-04-50 Stockholm
Telex: 854-10229
Cable: Raderscan-Stockholm
After switchboard hours, phone:
89-04-52 Gunnar Lindberg(Sales)
89-04-53 Anders Wadstad(Mng.Dir.)
89-04-54 Ingvar Ekstrom(Purch.)
89-04-55 Claes Breitholtz(Tech.dept.)
89-04-56 Astrid Gustafsson(Controller)

Allied Sheet Metal & Blowpipe, Inc.
9751 Linwood Avenue
Shreveport, Louisiana 71106
Phone: (318) 686-0590

RADER REPRESENTATIVES OUTSIDE THE U.S.A.

Anziel, Ltd.
P.O. Box 59-054 Mangere Bridge
32 Hastie Avenue
Mangere, Auckland, New Zealand
Phone: 663-969
Telex: 742-473
Cable: Anziel-Auckland
Contacts: Ian Gibbs
Robin C. Eade-General Mgr.

Anziel (Australia) Pty. Ltd.
6th Floor
No. 3 Bowen Crescent
Melbourne, Victoria 3004
Phone: 267-1333
Telex: 31308
Cable: Anziel-Melbourne
Contact: B.E. (Bruce) Highes-Manager

Peabody Holmes, Ltd.
P.O. Box B-7
Tumbridge, Huddersfield, England HD1 6RB
Phone: (0484) 22222,
Telex: 851-51306
Cable: Holmes-Huddersfield
Nightline: (0484) 33531
Contact:
B.J. Duncan-Chief Executive
A.J. Moyes-Technical Director &
Deputy Executive Chairman
W.A. Wilson-Director, Rotating Machinery
Division (Nightline:(0484)36263)
B. Holland-Director, Financial Controller
E. Taylor-RMDiv (Blowers)-Manager
(Nightline: (0484)30197)
S.N. Rowley-RMDiv (Blowers)-Engr. Mgr.
D.M. Holroyd-RMDiv (Blowers)-
Contracts Engineer
J. Whiteley-RMDiv (Blowers)-Spares & Service
R.J. Cowie-Director-Manufacturing
T. Cartledge-Controller-Blower Prod.

Peabody Holmes Limited
17 - 27 Garratt Lane
London
SW 18 4 BY

Mr. B. J. Duncan (Residence)
The Lumb, Lumb Lane
Almondbury, Huddersfield,
England HD4 6SZ
Phone: (0484) 29474

W.A. Wilson (Tony) (Residence)
191 Penistone Road
Huddersfield,
England HD5 8RW
Phone: (0484) 20551

Mr. Eric Taylor (Residence)
34 Lower Hall Road
Kirkheaton, Huddersfield
England HD5 0AZ
Phone: Huddersfield (0484) 48430

RADER REPRESENTATIVES OUTSIDE THE U.S.A.
(continued)

Estudios y Proyectos Industriales S.A.
Fuenterrabia 50, entlo
San Sebastian, Spain
Phone: (943) 46 7200
Telex: 36130 EPIS L E
Cable: EPI San Sebastian
Contact: Joaquin Huercanos

Mitsubishi Heavy Industries, Ltd.
5-1, Marunouchi 2 chome (LICENSEE-
Chiyoda-ku, Tokyo, Japan EXPORT)
Phone: (212) 3111
Telex: J22282, J22443
Contact: T. Watabe

George Spinelli Pty. Ltd.
P. O. Box 84026
Greenside
2034 Johannesburg
Phone: 01141-2120, 21, 22
Telex: 424377
Contact: George Kerr

Tecnil
Av. Republica 32-2 Dt
Lisboa 1, Portugal
Phone: 77 91 84/5/6/7
Telex: 16551 LUSTEC I
Contact: Mr. Loureiro

EPITEK
Passeo de los Olmos 5
Bajo Bidebieta 1
San Sebastian, Spain
Telex: 36122 EVAP

Unozawa Engineering Co., Ltd.
7th Floor ACE Building (LICENSEE-
No. 1-16-16 Ebisu-Nishi DOMESTIC)
Shibuya-ku, Tokyo, Japan
Phone: 03-476-0461
Telex: (781) 26714

Goro Shibayama
123 Kitamachi, Shoan, Suginami, Tokyo
Phone: 03-334-1465

Hideki Horie
Room 803, Ichigad Annex 1157-1 Ichigao-Cho
Midoriku Yokohama City Kanagawa Ken
Phone: 045 971-9485

Katsuo Goto
8-11 Omiya Plaza 331-28 Tsuchiya
Omiya City Saitama Ken
Phone: 0486-23-6449

Nobuharu Ishii
11-17 Moegino Midoriku Yokohama City
Kanagawaken
Phone: 045-973-1604

Villegas S.A.
Santa Fe 2445 - PISO 5 "B"
1412 Buenos Aires, Argentina
Phone: 824-3954
Telex: 9900 Public Booth Buenos Aires

NAME USDA/FS AID
DATE 7/21/80

SUBJECT: EQUIPMENT SUPPLIERS
Conveyors

MANUFACTURER: Rexnord
Vibrating Equipment Division
P.O. Box 13007 3400 Fern Valley Road
Louisville, KY 40213
(502)969-3171 Tlx: 20-4129
Ceil Platt, Mngr./Marketing Services

EQUIPMENT TYPE(S): Vibrating Conveyors, Feeders, Screens, Bin Discargers & Process Equipment for Bulk Material Handling

REFERENCE: Brochure No. 16912 - "Carrier Vibrating Equipment"
NWPC file - 1 copy

FOREIGN AGENCIES: See Sheets 2 & 3

Rexnord Inc.
Vibrating Equipment Division
3400 Fern Valley Road
Louisville, Kentucky 40213

INTERNATIONAL REPRESENTATIVES

EGYPT	EGP

Conintra International
9, EMAD EL DIN Street
Cairo, Egypt
91141 or 936438 (Telex 92024 & 92089)

S. E. Amin, President

KOREA	KOR

SHIN IL Engineering Company, Ltd.
C.P.O. Box 1292
Seoul, Korea
63-3680 (Telex K28316)

Byung Suh, Park

MEXICO	MEX

Bicor Diseno Cientifico S. A. de C. V.
Presa Sanalona 12
Mexico 10 D. F.
905-557-0746 or 905-557-6444
(Telex 177-3929)

Moises G. Bicas, General Manager
Moises Soffer, Divisional Manager
F. Hernandez, Technical Manager
Carmen Calderon, Traffic Manager

REXNORD-INTERNATIONAL REPRESENTATIVES ARE LOCATED IN THE FOLLOWING CITIES:

Amsterdam, Netherlands	Milan, Italy	Sao Paulo, Brazil
Singapore, Rep. of Singapore	Paris, France	San Juan, Puerto Rico
Usami, Japan	Berkshire, England	Caracas, Venezuela
Kempton Park, South Africa	Leeds, England	Bogota, Columbia
Copenhagen, Denmark	Brussels, Belgium	Savyon, Israel

ANY CORRESPONDENCE INVOLVING THE ABOVE LOCATIONS SHOULD BE ADDRESSED TO:

Supervisor, Engineered Equipment Sales
Rexnord International Inc.
c/o Post Office Box 2022
4501 West Greenfield Avenue
Milwaukee, Wisconsin 53201
414-643-2155

Name USDA/FS AID
Date 7-21-80

Sheet No. 3 of 3

INTERNATIONAL LICENSEES

Rexnord Inc.
Vibrating Equipment Division
3400 Fern Valley Road
Louisville, Kentucky 40213

REXNORD CANADA LTD. CAN

Conveyor and Components Division
1181 Sheppard Avenue, East
Willowdale, Ontario, Canada M2K-1C6
416-221-9361 (Telex 06-986-501)

F. C. Stapley (Fred), Marketing Mgr.
F. Bruckner (Frank), Mgr. Contract Sales
R. Matsugu (Dick), Project Engineer

ENGLAND ENG

Locker Industries Limited
P.O. Box 161
Warrington, WAI 2 SU, England
Phone: 011-44-925-51212
Telex: Dial 101 type 851 629508"

J. Dutton (John), Managing Director
H. Holmes (Harvey), General Sales Manager
R. L. Harrison (Les), Export Manager
S. Worrall (Stan), Chief Design Engineer

SOUTH AFRICA (ENG)

Lockers Engineers S.A. (Pty) Ltd.
P.O. Box 43021
Industria, Johannesburg, 200
Transvaal, Republic of South Africa
762-2553 (Telex: Dial 101 type 960-84683")

S. R. Woodward (Syd), Managing Director
A. D. Walker (Tony), Sales Director
K. J. Gannon (Ken), Mgr. Screening Div.
R. Pearson, Fdy./Conv./Process Division
J. McMorran (Jim), Engineering Director

BELGIUM (ENG)

Thomas Locker, S.A.
B 1350 Wavre Limal
Belgium
Phone: 32-10-416171
Telex: Dial 101 type 846" 59068 LOCKER B"

Jim G. Foster, General Manager
Andre Jamar, Commercial Manager
Jan Van de Pol, Sales Manager
Jean-Marie Ravet, Technical Manager
Bernard Bieva, Applications Engineer

AUSTRALIA

Locker Industries Pty. Ltd.
45 Keys Road - P.O. Box 181
Moorabbin, Melbourne, Australia 3189
Phone: 95-7744 (Victoria)
Telex: Dial 101 type 790 31319"

G. F. Ainsworth (Gordon), Mgr. Director
E. J. Phillipson (Ted), N.S.W. Manager
J. Smith (Jim), Sales Manager
A. Wells (Arnold), Sales Director

Sydney: 63 Whiting Street
Artarmon N.S.W. 2064
Australia
Phone: 439-2388

GERMANY GER

Uhde GmbH
Werk Hagen
BuschmuhlenstraBe 20
Postfach 4260

5800 Hagen 1
Phone: 011-49-2331-6921
Telex: Dial 101 type 841-823798"

Herr H. Heidemeyer (Herbert)
Herr Hans Schweinfurth

JAPAN JPN

Tamagawa Kikai Kaisha, Ltd.
13-12 Iwamoto-Cho 1 Chome
Chiyoda-Ku
Tokyo, Japan
Phone: 03-866-6241
Telex: Dial 102 type 781 2523243"

Kyoji Yoshino, President
Junji Tanaka, Manager of Sales
Koske Abe, Manager of Engineering

SWEDEN SWE

Bruks Mekaniska AB
P.O. Box 46
S-820 10 ARBRA-SWEDEN
Phone: 0278/40500
Telex: 81074

Rolf Jakobsson, Export Manager

G E N E R A T O R S & T U R B I N E S

NAME USDA/FS AED
DATE 7/24/80

SUBJECT: EQUIPMENT SUPPLIERS
Generators

MANUFACTURER: Louis Allis Division
Litton Industrial Products, Inc.
P.O. Box 2020 427 East Stewart St.
Milwaukee, WI 53201
(414)481-6000 TWX: 910-262-3115

Mike Buckna
Product Manager-Large AC Motors

EQUIPMENT TYPE(S): Generators & Motors

CAPACITY RANGE: Generators; 1,000-12,000 KW
Motors: 750W-7500KW (1-10,000hp)

FOREIGN AGENCIES: See Sheet 2 of 2

TURBINES & GENERATORS

MANUFACTURER: STAL-LAVAL TURBIN AB
S-61220 Finspong
Sweden
Telex 64040 STAVALS

EQUIPMENT TYPE (S): Steam turbines and electric generators

CAPACITY RANGE: Complete Range of turbines and electric generators above 1000 KW rating.

FOREIGN AGENCIES: Turbines available in various combination of extraction pressures and back pressures.

STAL-LAVAL

SUBSIDIARY COMPANIES

STAL-LAVAL APPARAT AB
Fack
S-581 01 LINKOPING 1
Sweden
Telex: 50068

S.A. STAL-LAVAL (Benelux) N.V.
Antwerp Tower, De Keyserlei, 5, B.22
B-2000 ANTWERP, Belgium
Telex: 33820

OY STAL-LAVAL Ab
Postfack 499
SF-00100 HELSINKI 10, Finland
Telex: 12594

STAL-LAVAL S.A.
62 rue Pergolese
F-75116 PARIS, France
Telex: 610282

STAL-LAVAL A.S.
Drammensveien 30
OSLO 2, Norway
Telex: 16443

STAL-LAVAL Limited
Crown House
London Road
MORDEN, Surrey, U.K.
Telex: 926719

STAL-LAVAL Inc.
400 Executive Boulevard
ELMSFORD, N.Y. 10523 USA
Telex: 710-5671 227

In addition there are representatives in 50 countries. Home office in Sweden to be contacted for these addresses.

NAME USDA/FS AID
DATE 7/18/80

SUBJECT: EQUIPMENT SUPPLIERS
Turbines

MANUFACTURER: The Terry Steam Turbine Company
P.O. Box 555 Lamberton Road
Windsor, Connecticut 06095
(203)688-6211 Tlx: 99-4495
Cable: Terrysteam
Carlton W. Kenzel, Marketing Analyst

EQUIPMENT TYPE(S): Steam Turbines - Gas Expanders
Reduction/Step-up Gears - Turbine-Generator Packages

CAPACITY RANGE: To 15,000KW (20,000hp)

REFERENCE: Terry Bulletins:

S-147-A	S-210A	S-239	NWPC
S-171	S-213	S-244	1 copy e
S-189A	S-230	S-245	
S-198	S-234	S-246	
S-199	S-237	S-248	

FOREIGN AGENCIES: See Sheets 2 thru 5
Foreign Maunfacturing Facilities:
Mexico (The Terry Steam Turbine Company)
West-Germany (Terry GMBH)

Products: Single & Multistage Turbines to 2240KW (3,000hp)

Name USDA/FS AID
Date 7-24-80

LITTON PRECISION PRODUCTS INTERNATIONAL, INC.

Contact	Location	Address	Telenet	Telex	Telephone
Louis Kok Willem VanDrunen	Belgium, Holland Luxembourg	Steenloperstraat 26 NL-Capalle A/D Yssel Holland	ZITS	23797	010-503902
Les Finn Bill Pierce	United Kingdom	95 High Street Slough, Buckinghamshire England	ZZSS	847548	0753-28267
Stephan Clod-Hansen Jean-Claude Sibi	France, Spain	58 Rue Pottier F78150 Le Chesney France	ZZUS	696267	03-9.55.21.04
Veine Agren Lars Malmsjo	Sweden, Norway Finland, Denmark	Warfuingesv 32 Box 30095 S10425 Stockholm Sweden	ZQES	17922	08-13 20 30
Roberto Lombardi Giulio Lepido	Italy	Via Arco 4 1-21021 Milan Italy	ZRMS	321649	02-3452236
Ernst Spiess	Switzerland	Gubelstrasse 28 Postfach 110 CH-8050 Zurich Switzerland	ZIDS	54905	01-3123544
Werner Sudaas Manfred Karcher	Germany, Austria, Comecon Countries	Oberfoehringerstrasse D-8000 Munich 80 Germany	ZZYS	524596	089-980547

FOREIGN OFFICES, TERRY STEAM TURBINE

MEXICO, MEXICO CITY

The Terry Steam Turbine Company
Apartado 105-182
Taine 29-301
Mexico 5, D.F.
Mexico

Tel: 905-250-8311
Tlx: 1771611

ENGLAND, SURBITON

The Terry Steam Turbine Company
Charter House
26 Claremont Road
Surbiton, Surrey
England, KT6 4RE

Tel: 01-390-4546
Tlx: 8952426 G

NETHERLANDS, THE HAGUE

The Terry Steam Turbine Company
Mail: P. O. Box 85930
The Hague 2508 CP
Netherlands

Street: Josef Israelplein 8
The Hague 2596 CP
Netherlands

Tel: 70-28-0082
Tlx: 34229

WEST GERMANY, OBERHAUSEN

Terry GMBH
42 Oberhausen 1
P. O. Box 10 16 29
4200 Oberhausen, West Germany

Tel: 208650075, 76 and
208651577
Tlx: 856626 TERRY D

FOREIGN OFFICES, TERRY STEAM TURBINE

PHILIPPINES, MANILA

The Terry Steam Turbine Company
12th Fl., Ramon Magsaysay Center
1680 Roxas Blvd.
Malate, Metro-Manila 2801
Philippines

Tel: 57-48-06 to 07
Tlx: 40466 TERRY PM

FOREIGN SALES AGENTS REPRESENTING THE TERRY STEAM TURBINE COMPANY

COSTA RICA, Alajuela

J. Halder Ltda
Apartado 285
Alajuela, Costa Rica
C. A.

Tel: 41-05-71
Tlx: HALDER

VENEZUELA, Caracas

Ortiz Y Mejia C.A.
Apartado 1809
Caracas, Venezuela

Tel: 02-45-3088
02-45-4481
Tlx: 22865 ORME

FRANCE, Paris

Defour Pere, Fils, & Cie
11 Rue Aspirant Dargent
Boite Postale 66
92302 Levallois-Perret
Paris, France

Tel. 758-54-50
Tlx: 620293

ITALY, Milan

Preda & Rudelli, S.A.S.
Via Vincenzo Monti, 75
Milan, Italy, 20145

Tel: 498-0451, 52, 53
Tlx: 332190 INTRAP 1

ARGENTINA, Buenos Aires

Cangallo 2231 PTA Baja
Segundo A
1040 Buenos Aires
Argentina

Tel: 48-2758
Tlx: 17782 LOCTY AR

BRAZIL, Rio de Janeiro

Comercio, Importacaco de Material
Tecnico Ltda. (CIMATEL)
Rua da Lapa, 120-12th Floor-Lapa
20.021 - Rio de Janeiro, Brazil

Tel: 021-244-5252
Tlx: 021-21770 CCMT-BR

CHILE, Santiago

Droste Ltda. Representaciones
Casilla 27
Santiago 1, Chile

Tel: 63192, 3, 4
Tlx: 3520315 DROSTE

DOMINICAN REPUBLIC, Santo Domingo

Altec International C. Par. A
Salvador Estrella Sadhala No. 20
(Altos)
Santo Domingo, Dominican Republic

Tel: 1-809-567-8947
Tlx: 3264275

FOREIGN SALES AGENTS REPRESENTING THE TERRY STEAM TURBINE COMPANY

TURKEY, Ankara

Ismail Tiner
P.K. 18 Kizilay
Ankara, Turkey

Tel: 178872
Tlx: 42677 IMT TR

GUATEMALA, Guatemala City

Hydroconsult Ltda.
12 Calle 6-40, Zona 9
Edificio Plazuela-Oficinas 401-402
Guatemala City, Guatemala

Tel: 31-0142, 31-5977
Tlx: NONE

AUSTRALIA, Melbourne

Gardiner Engineering Pty., Ltd.
Mail: P. O. Box 105
Bentleigh, Victoria, 3204
Australia

Street: 226 McKinnon Road,
McKinnon, Australia

Tel: 035785934
Tlx: AA35864 GARENG

MEXICO, Mexico City

Tecnotermica, S.A.
Colima 374
Mexico 7, D.F.
Mexico

Tel: 905-528-5642
Tlx: NONE

TAIWAN, Taipei

South Rich Corp.
P. O. Box 39-700
3rd Fl. No. 5, Shao-Shing S.St.
Taipei, Taiwan, R.O.C.

Tel: 02-3920447
02-3926637

Tlx: 24603 SOURICH

THAILAND, Bangkok

Trident International, Ltd.
G. P.O. Box 1877
18-20 Silom Road
Bangkok, Thailand

Tel: 2339773, 2339774
Tlx: 81020 TRIDENT TH

TERRY STEAM TURBINE

PUERTO RICO, San Juan

Sucesores de Abarca
P. O. Box 2352
San Juan, Puerto Rico 00903

Tel: 809-722-2080
Tlx: 3450024/365421

DENMARK, Hadsund

Jeumont-Schneider Scandinavia
Fredenslund
Als Odde
DK-9560 Hadsund, Denmark

Tel: 45-8-581446
45-8-581577

Tlx: 60729 PHAROS DK

SPAIN, Madrid

Ingeniera Y Desarrolo Industrial
S.A., (INDEIN)
Guzman El Bueno 133
Madrid 3, Spain

Tel: 253-9405
Tlx: 27327

ISRAEL, Haifa

Del-Ta Engineering Equipment, Ltd.
P. O. Box 389
Galgal Haplada St.
Herzlia 'B' 46103
Israel

Tel: 3930851
Tlx: 33481 DELTA IL

SAUDI ARABIA, Damman

Drilling Equipment & Chemicals Co
P. O. Box 132
Damman, Saudi Arabia

Tel: 22814, 23619
Tlx: 601063 DRECCO SJ

SOUTH AFRICA, Johannesburg

Iron Fireman, S.A. (PTY), Ltd.
P. O. Box 31567
Hampstead House
46 Biccard St.
Braamfontein 2017
Johannesburg, South Africa

Tel: 011398024, 5 &
39-3560, 786-4665
Tlx: 4-22304 SA

JAPAN, Tokyo

Marubeni Corporation
CPO Box 595
Tokyo 100-91, Japan

Tel: 03-282-3365
Tlx: J22326/J22328 MARUBENI

PHILIPPINES, Manila

B. B. Fischer & Co., Inc.
Mail: P. O. Box 7202
Manila International Airport
Metro Manila, Philippines
Street: 2nd Fl., ARC Bldg.
Maestranza Cor.Magallanes Dr.
Intramuros, Manila 2801
Philippines

Tel: 479861-479869
Tlx: 63483 BBFPN (EE)

KUWAIT, Safat

Al-Julaiah General Trading &
Contracting Co. W.L.L.
P. O. Box 26142
Safat, Kuwait

Tel: 833823, 826 and 832230
Tlx: 2560 A/B KIJLA KT
4195 A/B FAHDAN KT

SINGAPORE, (Singapore, Indonesia, Burma)

Ace Pressureweld Intl. (Pte), Ltd.
101 Kallang Way
Kallang Industrail Estate
Singapore 13, Singapore

Tel: 807-477
Tlx: JRI RS 24124

A I R P O L L U T I O N C O N T R O L

NAME USDA/FS AID
DATE 8/8/80

SUBJECT: Equipment Suppliers
Air Pollution Control

MANUFACTURERS: American Air Filter Co., Inc.
215 Central Avenue
Louisville, KY 40277
(502) 637-0011 Tlx. 20-4351

Frank E. O'Callaghan
Manager, International Services

EQUIPMENT TYPE(S): Dust Collectors: Dry Mechanical
Wet
Fabric
Electrostatic Precipitators

REFERENCE: See Sheet 2 of 2

FOREIGN AGENCIES: See Sheet 2 of 2

American Air Filter
AIR POLLUTION CONTROL PRODUCTS AND SYSTEMS

Better Air Is Our Business®

AMERICAN AIR FILTER CO., INC. • 215 CENTRAL AVE., LOUISVILLE, KY. 40277

Reference: DC-1-268F "Dust Collector Selection Guide"

200	267	295
206	272	298
207	276	302
208	277	304
209	279	312
AF-1-211	291	313
212	294	ES-1-336

FOREIGN AGENCIES: Regional Offices

Europe & the Near East:
AAF-International, SA--E.R.O.--
Egelenburg 2, P.O. Box 7928
Amsterdam, Netherlands
Tlx: 12372

Africa, Latin America & the Far East
AAF-International SA
215 Central Avenue
Louisville, Kentucky USA 40277
Tlx: 20-4351

CEA-CARTER-DAY'S RF DUST FILTERS

Partial list of users & applications

National Gypsum Co.
Alpena, MI .... Cement

Ralston Purina Co.
St. Louis, MO .... Soy Protein

Reserve Mining Co.
Silver Bay, MN .... Soda Ash

Pacific International Rice Mills
Greenville, MS .... Rice

Cargill, Inc.
Havana, IL .... Grain Dust

Adolph Coors Co.
Golden, CO .... Fly Ash

Weyerhaeuser Co.
Longview, WA .... Wood Dust

Thomasville Furniture Co.
Thomasville, NC .... Wood Dust

Central Soya Co., Inc.
Belmond, IA .... Soybeans

Mobil Chemical Co.
Woodland, CA .... Polyethylene

A. O. Smith Mfg. Co.
Kankakee, IL .... Iron Oxide

Wisconsin Public Service
Wausau, WI .... Coal

Kaiser Aluminum & Chemical Co.
Newark, OH .... Fly Ash

Froedtert Malting Corp.
Milwaukee, WI .... Malt

Prestolite Battery
East Point, GA .... Lead Oxide

Ft. Howard Paper Co.
Muskogee, OK .... Fly Ash

Atlantic Richfield Corp.
Ferndale, WA .... Soda Ash

Alabama State Docks
Mobile, AL .... Bauxite

Bunge Corp.
Destrehan, LA .... Grain

Continental Grain Co.
Beaumont, TX .... Grain

Husky Industries, Inc.
Dickinson, ND .... Charcoal

Sealed Power Corp.
Muskegon, MI ..... Metal Grindings

Abitibi Corp.
Alpena, MI .... Wood Dust

International Paper Co.
Gurdon, AR .... Sander Dust

Basin Electric Power
Beulah, ND .... Coal

B. F. Goodrich Chemical Co.
Pedricktown, NJ .... PVC

Ford Motor Co.
Dearborn, MI .. .. Foundry

Brush Wellman, Inc.
Elmore, OH . Copper Melting Furnace

University of Minnesota
Minneapolis, MN .... Coal

Public Service of N.H.
Merrimack, NH .... Coal

NAME USDA/FS AID
DATE 8/15/80

SUBJECT: EQUIPMENT SUPPLIERS
Air Pollution Control

MANUFACTURER: Ametek
Schutte & Koerting Division
Cornwells Heights, PA 19020
(215) 639-0900
Cable: Schutte Tlx. 84-5283

EQUIPMENT TYPE(S): Wet Scrubbers

APPLICATIONS: Gaseous and Particulate Applications in Air Pollution Control

REFERENCE: Ametek Bulletins: 7R Series
PC Series

FOREIGN AGENCIES: See Sheets 2 thru 4

AMETEK

Schutte & Koerting Division - Cornwells Heights, Pennsylvania 19020

INTERNATIONAL SALES REPRESENTATIVES

CANADA

Alberta, Calgary T2G 4C8

B Guthrie Engineering Co. Ltd.
1__1-_ Hastings Crescent S.E.
Phone: (403) 287-2483, 84
Telex: 038-21763

Alberta, Edmonton T6H 2H3
B. Guthrie Engineering Co. Ltd.
5905 - 103rd Street
Phone: (403) 434-8461
Telex: 037-2613

British Colombia, Vancouver
Axel Johnson Industries Ltd.
Process Equipment Division
1475 Boundary Road
Vancouver, B.C., V5K 4V2
Phone: (604) 291-2341
Telex: 04-354532

Nova Scotia Bedford B4A 2T3
Brian Engineering Limited
99 Rocky Lake Drive
Phone: (902) 835-8322
Telex: 019-22874

Ontario, Kitchener N2C IL3
Brian Engineering Limited
330 Manitou Drive
Phone: (519) 893-7474
Telex: 069-55234

Ontario, Rexdale (Toronto) M9W 4M3
Brian Engineering Limited
45 Shaft Road
Phone: (416) 248-0226
Telex: 06-989331

Ontario, Sarnie N7T 1Z6
Brian Engineering Limited
880 Philip Street
Phone: (519) 337-7591
Telex: 064-76143

Ontario, Toronto M411 1112
Mc Rae Engineering Equipment Ltd.
2 Thorncliffe Park Drive, Unit 31
Phone: (416) 422-3735, 36
Telex: 06-219663

Quebec, Montreal H4P 2A2
Brian Engineering Limited
2445 Duncan Road
Phone: (514) 735-1671
Telex: 055-60764

Quebec, Montreal H4P IC9
ROMATEC - RML, Division of
Robert Muddiman Ltd.
6535 Henri Bourassa Blvd. W.
Phone: (514) 332-9302
Telex: 05-826677

Saskatchewan, Regina S4P 1Y7
B. Guthrie Engineering Co. Ltd.
2231 Broad Street
Phone: (306) 352-2292
Telex: 071-2792 c/o TAS

Saskatchewan, Saskatoon S7K 3S1
B. Guthrie Engineering Co. Ltd.
P. O. Box 1720
Phone: (306) 242-8295
Telex: 074-2731

AMETEK

ARGENTINA
F. OLIVELLA CO.
Florida 253
1349 - Buenos Aires
Phone: 394-2290
Telex: (101 or 103) 390-9900
(public booth; also give phone number and F. Olivella)
Cable: OLIVELLA BAIRES

AUSTRALIA
H. G. Thornthwaite Pty. Ltd.
79 Victoria Avenue
P. O. Box 403
Chatswood, N.S.W. 2067
Phone: 40--4466
Telex: 790-23143
Cable: Orthorn, Sydney

BRAZIL
Saurer Ltda. (Licensee)
Rua Tenente Landy, 372
Sao Paulo, CEP 05068
Phone: 260-1495 (2435)
Telex: 391-11-22982

IEF Controles Automaticos Ltda.
Cx. Postal 1044
Sao Paulo CEP 02521
Phone: 266-7055
Telex: 391-11-23294

CENTRAL AMERICA
(Br. Honduras, Guatemala, Panama, Honduras, El Salvador, Nicaragua Costa Rica)
Incentro (Instrumentos Industriales Centro America S.A.
Avenida 9, No. 374
Apartado 271
San Jose, Costa Rica
Phone: 22-56-06
Telex: 303-2275

COLOMBIA
Panamerican-Engineering Ltd.
Apartado Aereo 54,064
Calle 59 #10-59 Ofc. 319
Bogota 2, Colombia
Phone: 255-3568, 255-3767
Telex: 396-45521 Code P-08
Cable: PANAMENG

INDIA
Stephen Balaram and Sons
317 Shahibag
Ahmedabad 380 004, India
Phone: 66341
Cable: Balind

ISRAEL
Techno Engineering Limited
5 Hagefen Street
P. O. Box 151
K. Bialick 27000
Haifa, Israel
Phone: 731018
Telex: 922-45119
Cable: Technoplan, Haifa

JAMAICA, WEST INDIES
Automatic Control Engineering Ltd.
31 De Carteret Road
(P. O. Box 208)
Mandeville
Jamaica, West Indies
Phone: 962-2773
Cable: FOXMATIC

LEBANON, LIBYA, UNITED ARAB EMIRATES JORDAN, EGYPT (UAR), KUWAIT, SAUDI ARABIA, IRAN, IRAQ, SYRIAN ARAB REP.
Energy Equipment International
P. O. Box 11-6785
Pavillon Bldg., Hamra Street
Beirut, Lebanon
Phone: 352188
Telex: 923-21738
Cable: ENERGIA

AMETEK

CHILE

Droste Ltda. Rep.
Casilla 27
Santiago 1,
Phone: 63192
Telex: (103) 352-1315
Cable: Drostecarl, Santiago

Imp. Tec. Vignola S.A.I.C.
Plaza Justicia, Peral 25
Casilla 93-V
Valparaiso,
Phone: 57073-56521
Telex: 392-30400
(public booth also give
telephone number and
name Mario Vignola,
CABLE: VIGNOL

MEXICO

Misco, S.A. (Licensee)
Dr. Jimenez No. 33
Mexico 7, D.F.
Phone: 578-9011
Telex: 0017-73-002
Cable: Missamex

AMETEK

PUERTO RICO
Badrena & Perez, Inc.
225 Carpenter Road
P. O. Box 1839
Hato Rey, P.R. 00919
Phone: 767-2467, 767-2475
Telex: (103) 345-0217
(all) 385-9047
Cable: FERBAD

Industrial Equipment Sales Co.
P. O. Box 94
Hato Rey, P.R. 00919
Phone: 809-754-1729
Telex:

SINGAPORE (includes Malaysia, Thailand, Indonesia & Brunei
OILTOOLS SINGAPORE
5th Floor, Tong Bldg.
302 Orchard Road
Singapore 0923
Phone: 7346711
Telex: 786-25288

SOUTH AFRICA, SOUTH-WEST AFRICA, ZIMBABWE (formerly Rhodesia), ZAMBIA, LESOTHO, SWAZILAND
A.F.H. DEVERS (PTY) LTD.
Div. Protea Holdings Ltd.
746 Sixth St., Wynberg 2012
(P. O. Box 39707-Bramley 2018)
Sandton, Transvaal, Rep. South Africa
Phone: 786-3710
Telex: 960-4-24914
Cable: Konimeter

A.F.H. DEVERS (PTY) Ltd.
P. O. Box 12, Goodwood
7460 Republic of South Africa
Telex: 960-5-7655 (Cape Town)

TAIWAN
Yung Loong Engineering Corp.
P. O. Box 24-33
Taipei, Taiwan, Rep. of China
Phone: 711070, 718812
Telex: 785-21329
Cable: Yiengcorp

UNITED KINGDOM AND EUROPE
William Boulton Ltd.
Licensee of Ametek/Schutte & Koerting Div.

Burslem, Stoke-on-Trent
Staffs, England ST6 3BQ
Phone: (0782) - 85658
Telex: 851-36166

URUGUAY
F. Olivella Co.
Florida 253
1349 Buenos Aires, Argentina
Telex: (101 or 103) 390-9900
(public booth; also give phone number and F. Olivella)
Phone: 394-2290

VENEZUELA
VENTECA (Venezolana de Tecnolozia,
Apartado 1942
Maracaibo
Phone: 061-919705
Telex: 395-62419

PROJECT ENERGY RESOURCES (VENTECA)
11511 Katy Freeway, Suite 280
Houston, Texas 77079
Phone: (713) 496-3350/3341
Telex: 790135

NAME USDA/FS AID
DATE 8/8/80

SUBJECT: EQUIPMENT SUPPLIERS
Air Pollution Control

MANUFACTURER: Belco Pollution Control Corp.
119 Littleton Road
Parsippany, NJ 07054
(201) 263-8900 Tlx. 710-987-8355

Paul B. Greetin
Vice President & Director
International Operations

EQUIPMENT TYPE(S): Air Pollution Control & Water Treatment Equipment

APPLICATIONS: See Sheet 2 of 2

BELCO POLLUTION CONTROL CORPORATION
PROCESSES FOR REMOVAL OF AIR AND WATER POLLUTANTS

119 LITTLETON ROAD, PARSIPPANY, N. J. 07054 (201) 263-8900
TWX #710 987 8355

5. APPLICATION

In order for Belco to determine if our Air Pollution Control Systems could advantageously be applied to any specific problems, it would be necessary for us to have certain data regarding each specific problem.

The information required consists of:

1. Source of gas
2. Type of fuel
3. Fuel analysis
4. Amount of particulate matter in gas
5. Particle size distribution
6. Gas Temperature
7. Operating Pressure
8. Actual gas volume
9. Dust collection efficiency desired
10. Any other operating data available

If you will describe a particular water treatment or air pollution control problem, our Applications Department will make an analysis and technical recommendations.

NAME USDA/FS AID
DATE 8/11/80

SUBJECT: EQUIPMENT SUPPLIERS
Air Pollution Control

MANUFACTURER: CEA-Carter International, Inc.
500 73rd Avenue N.E.
Minneapolis, MN 55432
(612)571-1000 Tlx. 29-0684
Cable: CAMACO

Eric A. Stanger
Executive Vice President

EQUIPMENT TYPE(S): Dust Filters, Pneumatic Conveyors, Grain & Rice Seed Cleaning Equipment

APPLICATIONS: Systems & Filters Used In Following Industries:

Grains	Seed
Wood	Coal
Chemicals	Minerals
Steel	Rubber
Food	Textiles

CAPACITY RANGE: Type RF Dust Filter Provides Dust Control Capacities to 2822 m^3/minute (100,000cfm)

PERTINENT INSTALLATIONS: See Sheet 2 of 2

REFERENCE: CEA-Carter International Bulletins:

GNL-C	DMF-3	NWPC file
DC-80	PR-2	1 copy each
RF-4	SRD-2	
RJ-2	HCD-3	

FOREIGN AGENCIES: Type RF Dust Filter Manufactured by CEA Subsidiary:
CEA Simon Day
Winnipeg, Manitoba, Canada
CEA-Carter International Provides Complete Installation Supervision World-Wide, Using Own Technicians or Factory Trained Supervisors

NAME USDA/FS AID
DATE 7/18/80

SUBJECT: EQUIPMENT SUPPLIERS
Air Pollution Control

MANUFACTURER: Croll - Reynolds Co., Inc.
P.O. Box 668 751 Central Avenue
Westfield, NJ 07091
(201) 232-4200 New York phone: (212)964-5784
TWX: 710-997-9642

EQUIPMENT TYPE(S): Jet-Venturi & Hi-Energy Ventury Fume Scrubbers; Packed Towers & Packaged Vent Scrubber System

APPLICATIONS: Wet Scrubbers For Dust, Odor & Toxic Gas Pollution Control

CAPACITY RANGE: 47 m^3/s (100,000 cfm) approximately

REFERENCE: CR Bulletin: FS 71
FS 71A
PT 74
HE 75
FS 76 1 copy NWPC file only

FOREIGN AGENCIES: & United States Representatives - See Sheet 2

BEST AVAILABLE DOCUMENT

Name USDA/FS AID

Sheet No. 2 of 2

ALABAMA/GEORGIA and TENNESSEE
GEORGE S. EDWARDS CO., INC.
P.O. Box 175
Pelham, Alabama 35124
Phone (205) 663-0707
(800) 633-8304

CALIFORNIA
MODOC ENGINEERING CORP.
3095 Kerner Boulevard
San Rafael, California 94901
Phone (415) 457-6811
BLAIR MARTIN COMPANY, INC.
849 Mission Street
P.O. Box 160
South Pasadena, California 91030
Phone (213) 682-2861

COLORADO
L. A. CHRISTOPHER COMPANY
P.O. Box 6339
Denver, Co 80206
Phone (303) 399-4320

FLORIDA
NOSUN ENGINEERING SALES, INC.
P.O. Box 5347
Lakeland, Florida 33803
Phone (813) 646-9664

ILLINOIS/INDIANA
•HARDIN & SIMMONS
407 South Dearborn Street
Chicago, Illinois 60605
Phone (312) 427-7002

LOUISIANA/MISSISSIPPI
BETZ ENGINEERING SALES CO.
P.O. Box 13248
New Orleans, Louisiana 70125
Phone (504) 486-5452
Baton Rouge, Louisiana
Phone (504) 926-5456

MICHIGAN
W. C. KNOWLES, INC.
P.O. Box 268
Birmingham, Mich. 48012
Phone (313) 642-4340

MISSOURI
ULMER EQUIPMENT CO.
1554 Fenpark
Fenton, Missouri 63026
Phone (314) 343-4606

NEW ENGLAND
ROBERT B. KREBS CO., INC.
P.O. Box 263
Ashton, Rhode Island 02864
Phone (401) 769-2560

NEW JERSEY
•MULLER PROCESS EQUIPMENT CO.
193 Paterson Avenue
Little Falls, N. J. 07424
Phone (201) 256-2052

NEW YORK
C.B.M. EQUIPMENT CORP.
3605 Eggert Rd., P.O. Box 266
Orchard Park, N. Y. 14127
Phone (716) 662-2542

NORTH and SOUTH CAROLINA
W. F. CRIST COMPANY, INC.
611 Templeton Avenue
Charlotte, North Carolina 28203
Phone (704) 372-3996

•Air Pollution Control Equipment Only
‡Vacuum Equipment Only

OHIO (South) KENTUCKY
REAMS CONTROLS, INC.
P.O. Box 15246
Cincinnati, Ohio 45212
Phone (513) 761-2500

OKLAHOMA
RENFRO & ASSOCIATES
1055 North Owasso Street
Tulsa, Oklahoma 74106
Phone (918) 582-0543

OREGON
‡BURHANS-SHARPE CO.
3777 S.E. Milwaukie Avenue
Portland, Oregon 97202
Phone (503) 235-6403
•C. P., INC.
2705 S.E. Milwaukie Avenue
P.O. Box 42214
Portland, Oregon 97202
Phone (503) 23?-4494

PENNSYLVANIA (East) DELAWARE and MARYLAND
•ALBERTS & ASSOC., INC.
1642 Norwell Drive
Philadelphia, Pa. 19115
Phone (215) 673-8290
‡GEORGE KELSO COMPANY
P.O. Box 34
Upper Darby, Pennsylvania 19084
Phone (215) 747-2303

PENNSYLVANIA (West) OHIO (North) and W. VIRGINIA
HINKEL & COMPANY, INC.
5 Brilliant Avenue
Pittsburgh, Pennsylvania 152??
Phone (412) 782-3225
7251 Beresford Road
Parma, Ohio 44130
Phone (216) 845-4237
South Charleston, West Virginia
Phone (304) 727-0100

PUERTO RICO
POWER EQUIPMENT, INC. (P.R.)
405-7 Condominio San Alberto
Condado Avenue
Santurce, Puerto Rico 00911
Phone (809) 725-5470

TEXAS
HENDRICKSEN COMPANY, INC.
P.O. Box 55505
Houston, Texas 77055
Phone (713) 461-2525
Dallas, West Texas
Phone (817) 626-3701
RANCO ENGINEERING SALES, INC.
P.O. Box 4662
El Paso, Texas 79914
Phone (915) 755-5271

VIRGINIA
BERKNESS CONTROL & EQUIPMENT CORP.
1506 Tomlynn St.
P.O. Box 6811
Richmond, Va. 23230
Phone (804) 359-5703

WASHINGTON
‡BURHANS-SHARPE CO.
P.O. Box [illegible]
Seattle, Washington 98124
Phone (206) 932-1030
•C. P., INC.
6201 104th Av., N.E.
Kirkland, Washington 98033
Phone (206) 827-4943

WISCONSIN
ADLAM EQUIPMENT CO., INC.
2401 North Mayfair Road
Milwaukee, Wisconsin 53226
Phone (414) 774-4350

FOREIGN REPRESENTATIVES

AUSTRALIA
MAXWELL INDUSTRIES
4 Esdaile Place
Arncliffe, N.S.W. 2205
Australia
Phone 02-599-3413

CANADA
JOHN BLACK LIMITED
765 Powell St.
Vancouver, B.C. V6A 1H5
Office 604 251-2232
Home 604 955-9387
MASDOM CORP. LTD.
83 Sunrise Avenue
Toronto, Ontario, Canada M4A 1B1
Phone (416) 751-2350
DENTECH LTD.
4769 Grier St.
Pierrefonds, Quebec
H9J 2A5 Canada
(514) 620-4812

ENGLAND
•CASTLETREE ENG. LTD.
26 Hadham Road
Bishops Stortford
CM23 2QS Herts
England

FRANCE
•SAPS ANTICORROSION
Le Coudray-En-Thelle
60790 Valdampierre
France

HOLLAND
PETRARCA BV
Postbus 7728
Schiphol-oost
Gebouw 112-k 230, Holland
Phone 020-45-87-21

INDIA
V. M. CORPORATION
Off Jakaria Bunder Road
Hira Baug, Sewri Khadda
Bombay, 15, India

ISRAEL
CHEM-OOTS
4 Hanushnah Street, P.O. Box 32020
Tel Aviv, Israel

MEXICO
F.I.T.S.A.
Apdo. Postal 330
Tlalnepantla, Mexico
Phone 562-28 01
562-28 34

SPAIN
TECHNISECO INGENIEROS, S. L.
Calle Belen, 4
Madrid, 4, Spain

TAIWAN
CONSTELLATION CO., LTD.
P.O. Box 24-74
Taipei, Taiwan

CROLL-REYNOLDS CO., INC.
751 Central Avenue, Westfield, New Jersey 07091

NAME USDA/FS AID
DATE 7/18/80

SUBJECT: EQUIPMENT SUPPLIERS
Air Pollution Control

MANUFACTURER: Joy Industrial Equipment Co.
Western Precipitation Division
4565 Colorado Boulevard 90039
P.O. Box 2744 Terminal Annex
Los Angeles, CA 90051
(213)240-2300 Tlx. 6-7233

George M. Fox
Manager
International Activities

EQUIPMENT TYPE(S): Electrostatic Precipitators, Baghouses, Gas Scrubbers, Cyclonic Collectors, Flue Gas Desulfuriztion Systems & Valves

APPLICATIONS: Control Air Pollution in Power Plants, Steel, Pulp & Paper, Cement & Lime, Sulphuric Acid, Copper & Aluminum, & Chemical Plants

REFERENCE: Western Precipitation Literature; See Sheet 2 of 3

FOREIGN AGENCIES: See Sheet 3 for Foreign Licensees

AUSTRALIA

Fowlerex Pty. Limited
P. O. Box 521
Artarmon, N.S.W. 2064
Australia

BRAZIL

Aero Mecanica Darma S.A.
R. Domingos Jorge, 92
CEP 04761 Sao Paulo
Brazil

CANADA

Joy Mfg. Co. (Canada) Ltd.
Precipitation Division
Major Holdings Square
235 King Street East
Kitchener, Ontario
N2G 2K8 Canada

ENGLAND

Steetley Engineering Ltd.
P. O. Box 20
Lenches Bridge, Brierley Hill
West Midlands, England DY6-8XA

FRANCE

Precipco Division de SICER S.A.
61, Rue Du Faubourg Montmartre
75009 Paris, France

GERMANY

Apparatebau Rothemuehle
Brandt & Kritzler
Postfach 40
5963 Wenden 5-Rothemuehle
Federal Republic of Germany

Walther U. Cie Aktiengesellschaft
Waltherstr. 51
Postfach 85 03 80
5000 Kooln 80 (Dellbrueck)
West Germany

ITALY

Compagnia Italiana Forme Acciaio
Viale Rimembranze
20026 Novate Milanese
Milan, Italy

JAPAN

Sumitomo Heavy Industries, Ltd.
Air Pollution Control Department
Engineering Div. Machinery Group
1, Kanada Nishikicho 2, Chome,
Chiyoda-Ku
Tokyo 101, Japan

MEXICO

Maquinas De Proceso, S.A. de C.V.
Carret, Constitucion Km. 228.5
Apdo. Postal No. 438
Queretaro, Qro., Mexico

SOUTH AFRICA

Dorbyl Projects and Construction
(Pty.) Ltd.
P. O. Box/Posbus 6253
Johannesburg 2000
Republic of South Africa

SPAIN

General Metalurgica, S.A.
Epalza 8
Bilbao 7, Spain

PERU

Joy Manufacturing Co. (Peru) S.A.
Av. De La Marina 2673, Third Floor
San Miguel, Casilla 3111
Lima 32, Peru

NAME USDA/FS AID

SUBJECT: EQUIPMENT SUPPLIERS
Air Pollution Control

MANUFACTURER: Wheelabrator-Frye Inc.
Air Pollution Control Division
600 Grant Street
Pittsburgh, PA 15219
(412)288-7300 Tlx. 86-6288

EQUIPMENT TYPE(S): Fabric Filter Collectors, Electrostatic Precipitators

APPLICATIONS: Air Pollution Control

REFERENCE: Brochures:

APC 4	APC 1	RC-1	NWPC file
APC 13	APC 8		1 copy each
APC 6	APC 14	Bulletin #10	
APC 12	JV 1		
APC 10	WWC 2		

FOREIGN AGENCIES: See Sheet 2 for Foreign Sales Offices

Air Pollution Control Division
Wheelabrator-Frye Inc.

ENACON, Ltd.
235 Bay Street
Botany, Sydney 2019
Australia
Telex: 27363 GECON
Phone: 666 9045

INDABRATOR, Ltd.
NSE Estate
Goregaon East
Bombay 400 063 India
Telex: 011 4980
Phone: 69-43-01/02-03

Sintokogio, Ltd.
Toyoda Building
No. 7-23, 4-Chome
Mei-Eki, Nagoya 450
Japan
Telex: 442-7437 SINTO J
Phone: (052) 582-9211

Wheelabrator Corp. of Canada
401 Wheelabrator Way
Box 1000 L9T 4B7
Milton, Ontario
Canada
Telex: 06 960 283
Phone: (416) 844-1550

Wheelabrator Sinto do Brasil
Caixa Postal 4584
01000 Sao Paulo
Brasil
Telex: 23659
Phone: 446-4333

Wheelabrator de Mexico
Apartado M-7472
Mexico 1 D.F.
Mexico
Telex: 017 74567
Phone: 576-6122

Tilghman Wheelabrator, Ltd.
P. O. Box 60
Altrincham
Cheshire WA 14 5EP
England
Telex: 668-945
Phone: 928-6388

Tilghman Wheelabrator, S.A.
P. O. Box 1722
Kempton Park 1620
Republic of South Africa

Telex: 8-2319
Phone: 975-9380

REFERENCE: Western Precipitation Literature

General Catalog 300-1
Basic Handbook

	NWPC file
DS-1	1 copy
P-150	1 copy
WPU-110	--
CB-200-1	1 copy
DF-102-2	1 copy
S-100	1 copy
M-274	--
V205R	

NAME USDA/FS AID

SUBJECT: EQUIPMENT SUPPLIERS
Air Pollution Control

MANUFACTURER: Zurn Industries, Inc.
P.O. box 2206 275 North First Street
Birmingham, AL 35201
(205)252-2181 Tlx. 5-9726

John S. Alcorn, Jr.
Sales & Marketing Manager

EQUIPMENT TYPE(S): Mechanical Collectors, Scrubbers, Fabric Filters-Pulse, Shaker & Reverse Air.

APPLICATIONS: Control of Gaseous or Solid Particulate Emissions Discharged from industrial, Commercial or Municipal Installations

REFERENCE: Zurn Bulletin No. G03

NWPC file
1 copy each

FOREIGN AGENCIES: See Sheet 2 of 2

NAME USDA/FS AID

DATE 7/8/80

SUBJECT: EQUIPMENT SUPPLIERS
Conveyors

MANUFACTURER: McConnell Industries
117 Citation Court
P.O. Box 26210
Birmingham, AL 35226
(205)942-3321 Tlx. 5-9796

K. V. Lutes

EQUIPMENT TYPE(S): Wood Fuel Burner System:
(1) Receiving, Preparation & Storage;
(2) Metering & Delivery;
(3) Burner System;
(4) Heat & Air Distribution;
(5) Operating Controls

DESIGN FEATURES: Wood Burner Designed as a Complete Combustion System for Firing Clean, Relatively Dry, Fine Particled, White Wood Waste or Wood Residues

APPLICATIONS: Replacement of Natural Gas, Low Pressure Gas (lpg) & Fuel Oil Fired Burner on:

Direct Fired Lumber Dry Kilns
Rotary or Stationary Product Kilns
Veneer Dryers
Other Special Applications

CAPACITY RANGE: See Sheet 2 of 2

PERTINENT INSTALLATIONS: Conversion of Lumber Dry Kilns from oil or gas to wood fueled burner: (5) Alabama; (3) Arkansas; (5) Georgia; (6) Louisiana; (11) Mississippi; (7) North Carolina; (4) South Carolina; (2) Texas; (3) Virginia; Rotary Product Dryers: (1) AR; (1) GA; (2) GA; (2) NC; (2) SC; (2) VA; (2) WI; (1) Davao, Mindiao P.I.; (1) LaSarre, Quebec, Canada. Specail Energy Recovery & Utilizati (Char Furnace) - Masonite Corp., Pachuta, MI.

REFERENCE: Unnumbered McConnell Brochures
Bulk Storage Structures, Bulletin 6040, Koppers Co., Inc.
Industrial Hammermills, Catalog No. IHW-77 Jacobson MchcWks. Inc.

NAME USDA/FS AID
DATE 7/8/80

McConnell Industries

CAPACITY RANGE: 4 Basic Models & Outputs:

Output Range with 5 to 1 Turndown Ratio

Model	GJ (GIGA Joule)	(10^6 BTU)
30	6.3-11.6	(6-11)
36	12.7-24.3	(12-23)
42	25.3-32.7	(24-31)
48	33.8-42.2	(32-40)

NAME USDA/FS AID
DATE 10/21/80

SUBJECT: EQUIPMENT SUPPLIERS
Boilers

MANUFACTURER: Weiss USA Information Center
P. O. Box 8
Woxall, PA 18979
(215) 234-8000 Tlx. 83-6455

Karl H. Middelhauve
Consultant

EQUIPMENT TYPE (S): Mini Boilers

APPLICATIONS: Burns sanderdust, sawdust, shavings, chips, solid cutoffs (dry or green), solid rippings (dry or green up to 4 ft. long), unhogged bark, paper, walnut shells, bagasse, tobacco dust, spent coffee grinds.

CAPACITY RANGE: 40 to 160 hp

REFERENCE: Brochure NWPC File
1 c/c

Zurn Steam Generating Systems

Name: USDA/FS AID
Sheet No. 2 of 2
Job No. NWPC 231014

Custom Designed To Customer Requirements

Design	Capacity Range	Description
Keystone® Watertube Steam Generators	(6,000-600,000 pph) 0.76-76 kg/s	Factory-assembled or modularly field-erected for firing gas and/or oil and/or carbon monoxide (CO_2) and other waste gases. Request brochure SB-71
"VL" Watertube Steam Generator	(10,000-60,000 pph) 1.26-76 kg/s	Factory-assembled for firing coal, wood or other solid wastes as well as combination/future solid, gas, oil. Request brochure SB-81
"VC" Watertube Steam Generators	(50,000-150,000 pph) 6.3-18.9 kg/s	Field-erected, bottom-supported, cross-drum for firing coal, wood or other solid wastes as well as combination/future solid, gas, oil. Submit requirements (Brochure being revised)
Cross-Drum Watertube Steam Generators	(100,000-1,000,000 pph) 12,6-126 kg/s	Field-erected, bottom or top supported, single or multiple pass. Able to be designed for firing most gaseous, liquid, or solid fuels as well as for waste heat or waste fuel energy recovery. Request brochure SB-74
Waste Heat Energy Recovery	(20,000-1,000,000 pph) 2.5-126 kg/s	Available in a variety of two and three drum watertube designs including extended-surface, non-extended surface (baretube) and gas turbine exhaust. Custom firetube designs also available. Submit requirements (Brochures being revised)
Auxiliary Components	Any Capacity	Economizers Request brochure SB-80; Spreader Stokers Request brochure SB-62; Steam Purity Components Request Flyers SG-5, SG-6

ZURN a step ahead of tomorrow

ZURN INDUSTRIES, INC.
ENERGY DIV
1422 EAST AVE.
ERIE, PA. U.S.A. 16503
PHONE 814/452-6421
TELEX 91-4473

Form No. SB 68 5/78

Foreign Licensees:

Thermax (India) Pvt. Limited
D-13, M.I.D.C. Industrial Area
Chinchwad, Poona 411 019
India

Rohinton D. Aga, Managing Director
Prakash M. Kulkarni, Product Manager

Telephone: 83550/83303/04/05/06 83062/83063
Telex: 145-334

Nachi-Fujikoshi Corp.
World Trade Center
2-4-1 Hamamatsucho Shiba
Minato-KU
Tokyo, Japan

Telephone: 435-5111

K. Ohwada, President
T. Inokuchi, Mgr.-Chem. Engr.
Jun Takeuchi, Gen.Mgr.
Industrial Equipment Div.

C O N T R O L S

NAME USDA/FS AID
DATE 8/28/80

SUBJECT: EQUIPMENT SUPPLIERS
Controls

MANUFACTURER: The Foxboro Company
38 Nepon Set Avenue
Foxboro, MA 02035
(617)543-8750 Tlx: 927-602
Cable: Foxco Foxboro TWX 710-346-7630

EQUIPMENT TYPE(S): Products used to measure, analyze, indicate, record, & control process variables such as flow, temperature, pressure, level, & composition. Products include instruments that sense & transmit these variables & computer-based systems to control entire plants.

APPLICATIONS: Industries served are: Chemical, Oil & Gas, Power, Pulp & Paper, Food, Metals, Minerals, Marine, & Textile

REFERENCE:	Forboro Bulletins:		NWPC file
		A-31	1 copy
		B-46	1 copy
		C-401A	2 copy
		M-13	1 copy
		Pub 509 7.5M	1 copy

FOREIGN AGENCIES: See Sheets 2 thru 9

4. FAR EAST AND ASIA

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CABLE FOREAST SINGAPORE
Phone: 623-233

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Levatus (Bangladesh) Ltd.
74-Motijheel Commercial Area
Dacca, Bangladesh
Tlx. ARLINKS DAC 703
A/B ARLINKS DAC 703
CABLE LEVATUS DACCA
Phone: 25-1867

HONG KONG

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Hong Kong
Tlx. 73049 CECO HONG KONG
A/B 73049 CECO HX
Cable: CECOINTER HONG KONG
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Castle Peak Road, 9½ miles
Tsuen Wan, New Territories

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Bombay 400 023 INDIA
Tlx. 112-284 Bombay
A/B 11 2284 BATL IN
Cable; BATLIBOICO, BOMBAY
Phone 243-823
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Bonbay 400 023 India

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A/B 043-215
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Phone 2-7216

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Cable: BATLIBOICO
Phone: 238831

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A/B 45838 FOXJAKIA
Cable: FOXJAK JAKARTA
Indonesia
Phone 36-3820, 35-9051,2,3

Branch

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105-107 Jend Basuki Rachmat
Surabaya, Indonesia
Tlx. 31434 KOPER SB - A/B also
Cable FOXSUB SURABAYA
Indonesia
Phone: 41454-59 Ext. 35

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CHIYODA-KU
Tokyo
102 JAPAN
Tlx. J25857 FOXTOK
A/B FOXTOK J25857
Cable FOXBOROCO TOKYO
Phone 03 264-1046

Marine Projects

Nissho-Iwai Co., Ltd.
4-5 Akasaka 2 Chome
MINATO-KU
Tokyo
107 JAPAN
Tlx. J22233
A/B J22233
Cable: NISSHOIWAI TOKYO
Phone 588-4583

KOREA
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Hansaeng-Foxboro Co. Ltd.
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Seoul, Korea
Tlx. Hanfox K24900
A.B HANFOX K24900
Cable KOSILK SEOUL
Phone 269-2177 9
Street adress:
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18th Floor
Automobile Insurance Bldg.
Chung-Ku, Seoul, KOREA

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Foxboro (Malaysia) Sdn. Bhd.
130A Jalan Kasah
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Kuala Lumpur, 23-10, Malaysia
Tlx. MA 30517 FOXMAY
A/B MA 30517 FOXMAY
Cable FOXMAY KUALA LUMPUR
Phone: 941-666, 941-675

PAKISTAN

Manstock Engineering Co., Ltd.
P.O. Box 7576
Karachi 3, Pakistan
Tlx. 2-5436 MANS PK
A/B --
Cable COSMOTRADE KARACHI
Phone 51-0138, 51 0139
Street address:
100 Farid Chambers
Abdullah Haroon Road

Branch (Lahore Office)

Al-Sarwar Building
Bank Squre, The Mall
Lahore, Pakistan

PHILIPPINES

Lietz Zulueta Capital, Incor.
P.O. Box 511
Makati Commercial Center
Makati, Metro Manila 3117
Philippines
Tlx. 722 22497 LZI PH (RCA)
722 22247 SHR OH (RCA)
742 45604 LZI PM (ITT)
A/B 2247 SHR PH
Calbe: SHURDUT MANILA
RUDLIETZ MANILA
Phone 88 26 56
Street address:
Lietz Zulueta Capital Incorp.
Kaiaw Ledesda Condominium
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Legaspi Village
Makati, Metro Manila 3119
Philippines

SINGAPORE

Foxboro Far East Pte. Ltd.
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A/BRS21193 FOXSIN
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Ayer Rajah Industrial Estate
Singapore 0513

SRI LANKA

S. V. Industries (Ceylon) Ltd.
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Colombo 8, SRI LANKA
Cable: SEETALUK COLOMBO
Phone: 93865

TAIWAN

Siantek Company Limited
P.O. Box 569
Taipei, Taiwan
Tlx. 11091
A B 11091 SIANTEK
Cable SIANTEK TAIPEI
Phone 551-8749, 561-4545,
571-2909
Street address:
36 Chang-An Eastroad
Section 1

THAILAND

The Delta Trading Company Limited
P.O. Box 11-164
Bangkok, Thailand
Tlx. TH 82099 DELTACO
BANGKOK
A/B DELTACO TH2099
Cable DELTATRADE BANGKOK
Phone 314-3967
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2085-87 Petchburi Ext. Road

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A/B FOXAUS AA 31097
Cable FOXAUS MELBOURNE
Phone: 726-6455
Street address: Maroondah Highway

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Cable FOXAUS MELBOURNE
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A/B FOXAUS AA93849
Cable FOXAUS PERTH
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A/B ESKIMOAK NZ2977
Cable ESKIMO NEW PLYMOUTH
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2. CANADA

AREA HEADQUARTERS

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290
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3. MIDDLE EAST AND AFRICA

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A/B 21725 FOXME JO
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ARAB REPUBLIC OF EGYPT

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GHANA

SONIC Control &
Engineering Services, Ltd.*
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Tesco International Ltd.*
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CABLE TESCO TELEX TEHRAN
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Shahreza Avenue

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PHONE 44841

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A/B AL RASHED KWT
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Street address
45 Abeokuta Street
Ebute-Metta

OMAN

Oman Oil Industry Supplies &
Services Co. (OOISS)*
P. O. Box 127
Muscat, Sultanate of Oman
TLX MB 3258 MUSTRD
A/B
CABLE TIJARAH
PHONE 610061

QATAR

Business Communications Qatar*
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Qatar, Arabian Gulf
TLX 4454
CABLE BCQ/DH
A/B 4454 BCQ DH
PHONE 325851

SAUDI ARABIA

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DAMMAM, SAUDI ARABIA
TLX 601073 TIG TESCO
A/B 601073 TESCO SJ
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PHONE 832-2201

SYRIA

Akramer Organization*
P. O. Box 4966
DAMASCUS, SYRIA
CABLE AKRAMER
PHONE 229511
220987

UNITED ARAP EMIRATES

NEAR EAST PROJECT
AND TRADING CO.*
P. O. Box 6493
ABU DHABI, United Arab Emirates
TLX 3350 PORGUL AH
A/B
PHONE 25452
Street address
Flat 901
Shiekh Mubarak Bldg.
(Opposite Toronto Dominion)
Khalifa Street

* Representative under contract to The Foxboro Company to provide [illegible]

4. FAR EAST AND ASIA

AREA HEADQUARTERS

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A/B FOXSIN RS21193
CABLE FOXEAST SINGAPORE
PHONE 623-233

BANGLADESH

LEVATUS (BANGLADESH) LTD.*
74-Motijheel Commercial Area
Dacca, BANGLADESH
TLX ARLINKS DAC 703
A/B ARLINKS DAC 703
CABLE LEVATUS DACCA
PHONE 25-1867

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CABLE CECOINTER HONG KONG
PHONE (12) 4202911/4
Street address
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INDIA

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